ESTABLISHMENT OF OPERATIONAL GUIDELINES FOR TEXAS COASTAL ZONE MANAGEMENT

Final Report on

Estuarine Modeling

Center for Research in Water Resources
Division of Natural Resources and Environment
The University of Texas at Austin

E. Gus Fruh
Environmental Health Engineering
Center for Research in Water Resources
Project Director

Other Co-Principal Investigators:
William L. Fisher, Bureau of Economic Geology
Kingsley Haynes, LBJ School of Public Affairs
Jared E. Hazleton, LBJ School of Public Affairs
Joseph F. Malina, Jr., Environmental Health Engineering
Frank D. Masch, Jr., Civil Engineering
Carl H. Oppenheimer, Marine Science Institute at Port Aransas
Joe C. Moseley II, Texas Coastal and Marine Council

Project Coordinator:
Michael J. Cullender, Center for Research in Water Resources

Research Associates:
Thomas E. Isensee, Marine Science Institute at Port Aransas
Robert S. Kier, Bureau of Economic Geology
William T. Kleeman, Jr., LBJ School of Public Affairs
George W. Murfee, Environmental Health Engineering
James S. Sherman, Environmental Health Engineering
Gerald M. White, Department of Geography
William A. White, Bureau of Economic Geology

Project Secretary:
Sandy Bryant, Center for Research in Water Resources

Liaison Investigator with the Division of Planning Coordination, Office of the Governor of Texas:
Joe B. Harris, Interagency Council on Natural Resources and the Environment

ESTABLISHMENT OF OPERATIONAL GUIDELINES FOR TEXAS COASTAL ZONE MANAGEMENT

Final Report on ESTUARINE MODELING

Prepared by

George W. Murfee, Research Associate
Frank D. Masch, Jr., Co-Principal Investigator
E. Gus Fruh, Co-Principal Investigator

for

Research Applied to National Needs Program
National Science Foundation
Grant No. GI-34870X

and

Division of Planning Coordination
Office of the Governor of Texas
Interagency Cooperation Contract No. IAC (74-75)-0685

May 31, 1974

Coordinated through
Division of Natural Resources and Environment
The University of Texas at Austin

This is one in a series of eight final reports describing progress on this research project for the period June 1, 1972, to May 31, 1974. The eight reports are:

- Summary
- Economics & Land Use
- Water Needs & Residuals Management
- Estuarine Modeling
- Resource Capability Units
- Biological Uses Criteria
- Example Application I. Implications of Alternative Public Policy Decisions Concerning Growth & Environment on Coastal Electric Utilities
- Example Application II. Evaluation of Hypothetical Management Policies for the Coastal Bend Region

ACKNOWLEDGMENTS

This research has been supported by the National Science Foundation, Research Applied to National Needs Program, through Grant GI-34870X, and by the Office of the Governor of Texas through Interagency Cooperation Contract IAC (74-75)-0685.

Messrs. Bheskara Reddy Penumalli, Walter Lambert, Richard B. Wise, James Scaief, and Ms. Sharon Kleeman have provided invaluable assistance in performance of the work and evaluation of results contained within this report.

The authors are grateful to several individuals and agencies for their assistance at various times thrroughout this project and with the preparation of this report. Special acknowledgments are due Messrs. Lewis B. Seward, Seth D. Burnitt, Jack Nelson, Don Rauschuber, and other staff at the Texas Water Development Board for making available their models of the combined Corpus Christi-Aransas-Copano Bay System and for providing much of the data compiled into the recent Data Packages used in this study. Their interest and suggestions during the course of this work have been especially helpful. Special thanks are also due Dr. Robert J. Brandes of Water Resources Engineers, Inc., Austin, Texas, for his advice and assistance in modifying the TWDB models to the versions now being used in this project and in the general operation of the models for different Data Packages.

The other principal investigators and the project staff also are acknowledged, in particular Mr. James S. Sherman for his time and efforts in providing information on river inflows and wastewater loadings and Ms. Sandy Bryant for her help in the typing and preparation of this report.

SUMMARY

The objective of this task force during the two-year study has been to adapt existing hydrodynamic and conservative water quality transport models available for the bays and estuaries of the Coastal Bend Region to determine the spatial distribution of various water quality constituents affected by inflows entering and wastewater discharged into these aquatic environments. Emphasis in the second year has been placed on developing non-conservative water quality transport models specifically for Corpus Christi Bay, which was expected to receive the major environmental impact from projected municipal and economic growth in the Coastal Bend Region and where overall project needs may require additional model resolution and computer storage not available in presently calibrated models.

The initial simulation work utilized existing hydrodynamic and salinity transport models of a system which included not only Corpus Christi but also Aransas and Copano Bays. For the purposes of this study, this larger model was modified to include only the bay waters of the primary study area. This modification required establishment of the boundary conditions at the point the original model was cut off.

Due to the importance to the water quality transport models of the net flows and depths generated by the hydrodynamic model, a high degree of reliability in the computations of the hydrodynamic model needed to be established. Verification of both the hydrodynamic and salinity transport models has been accomplished using data collected during 1972-73 in Corpus Christi Bay. Sensitivity tests also were performed using the hydrodynamic and salinity transport models. In the hydrodynamic model, the response of tidal amplitudes and flows were determined for changes in roughness, wind stress and evaporation coefficients. The sensitivity of the salinity transport model was determined for dispersion coefficients and evaporation rates.

Water quality transport models which simulate the spatial distribution in Corpus Christi Bay of total phosphorus, biochemical oxygen demand, dissolved oxygen, and the various nitrogen cycle constituents were developed. The models were tested for four Data Packages obtained at different seasons which contained the requisite hydrodynamic, meteorologic, and water quality data.

The Corpus Christi Bay conservative transport model was modified to include a first order reaction term which behaved as a sink in the single constituent total phosphorus transport model. The order of magnitude and trend of the observed total phosphorus changes in Corpus Christi Bay were well simulated by the model. However, the model can only be considered "calibrated"

because different rate coefficients (although of the same order of magnitude) had to be used for the four Data Packages and the coefficient could not be correlated to environmental conditions such as temperature and salinity.

Similar results were found with the BOD_5 modeling effort. Unfortunately field data used to calibrate the dissolved oxygen model were collected in daylight hours and supersaturation always existed. Hence, the multi-component reaction dissolved oxygen model could not be "calibrated". A multi-component first order reaction model was developed for the nitrogen cycle including degradation of organic nitrogen, nitrification and plant uptake, but not plant settling, decomposition, and nitrogen recycling. Agreement between observed and computed nitrogen values was acceptable, the same reaction coefficients being applicable to all four Data Packages.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (CONTINUED)

CHAPTER I
INTRODUCTION

The evaluation of the environmental impact of various land use and/or water quality control policies on bay and estuarine waters places a major emphasis on the ability to analyze advective and other transport processes in tidal waters. These transport processes include diffusion, dispersion and differential convection of reactive and non-reactive substances. In aggregate, they determine the migration and dilution of various pollutants and toxic materials as well as the distributions of certain naturally occurring organics and inorganics essential to a productive and balanced estuary ecosystem.

A basic requirement for most transport (water quality) studies in a bay or estuary is that the tiday hydrodynamics be known or readily obtainable. This includes the time and area-wise distributions of tidal amplitude and tidally generated currents. For a given system bathymetry, dependent variables must be determinable under a variety of external influences including the fundamental tidal excitation, inflows, diversions, winds, rainfall, runoff, evaporation and density gradients. Some of these data can be obtained from field observations, or from assumptions and simplified analyses. It is rare, however, when all the required information is known with sufficient detail to undertake a comprehensive analysis of mass transport phenomena in the system.

Basically, mass transport analysis requires that the advective and dispersive components be known at every point in space and time over which a solution is sought. These are the components which can be determined only from the spatial and temporal distributions of tidal amplitude and currents. At most, carefully planned data collection programs can continuously measure these hydrodynamic parameters at a few selected locations. Thus, the need to bridge-the-gap or fill in the hydrodynamic information throughout the system is indicated. It is for this reason that investigators now turn to analogs, physical and mathematical models, and stochastic methods.

Objectives and Scope

The basic objective of the project has been to adapt existing hydrodynamic and transport models available for the principal bay and estuarine waters of the Coastal Bend Council of Governments (COG) region to determine the spatial distribution of various water quality constituents as impacted by projected inflows entering and wastewater discharged into these aquatic environments. Emphasis has been placed on developing water quality transport models specifically for Corpus Christi Bay, which is expected to receive the major environmental impact from projected municipal and economic growth in the

Coastal Bend Region and where project needs may require additional model resolution and computer storage not available in presently calibrated models.

More specifically, this project has addressed the following several subtasks.

1. Selection, modification and adaptation of existing tidal hydrodynamic and salinity transport models to Corpus Christi Bay.
2. Further verification of the selected models using recent prototype data.
3. Sensitivity testing of the hydrodynamic model to variations in wind stress coefficient, Manning roughness coefficient, and evaporation coefficients.
4. Sensitivity testing of the salinity transport model to variations in dispersion coefficients and evaporation coefficients.
5. Extension of the salinity transport model solution technique to biochemical oxygen demand and dissolved oxygen, total phosphorus, and the various species of the nitrogen cycle.
6. Simulations of estuarine system response to conditions corresponding to different hypothetical coastal zone management policies for the Coastal Bend COG.

In subtask 6, the Estuarine Modeling Task Force "bridged the gap" between the Water Needs and Residuals Management Task Force and the Biological Uses Criteria Task Force. The former provided the freshwater and wastewater loadings to the Corpus Christi Bay System. The latter was supplied the distributions of the various water quality constituents.

Subtasks 1-4 have been discussed in the Interim Report for this task force (1). [The pertinent sections of this report are presented for the benefit of the reader in Appendix A.] Subtask 5 is covered in this report. Subtask 6 is presented in a separate multidisciplinary final report covering the policy evaluation efforts of the entire project team.

Previous Work

Some of the earliest documented water quality modeling work in Corpus Christi Bay was that described in (2). This study involved a modified tidal prism model of Corpus Christi Bay set up by Masch and Urban in 1966 at The University of Texas at Austin. The primary purpose of this model was to make estimates of physical exchange for preliminary studies of marine resources and fresh water requirements. This model had its genesis in the classical tidal prism concept and permitted the calculation of tidal exchange and exchange coefficients between various parts of Corpus Christi Bay.

At about this period of time, a model using a salinity balance was proposed by Lockwood and Carothers (3). The primary purpose of this model was to provide a methodology to support a concept wherein tidal inlets and passes were to be used to maintain salinity control through a balance between precipitation runoff, evaporation and Gulf exchange within a given bay system. For Corpus Christi Bay, it was proposed that the natural runoff from the Nueces River be supplemented with Gulf water through Corpus Christi and Boggy Slough Passes and Demit Island Channel. Since both the above approaches were highly empirical, the major limitation to this application was lack of reliable field data.

Over the period 1967-1971, Masch and his associates (4,5,6,7,8) developed a conceptual mathematical modeling approach linking tidal hydrodynamic and various mass transport models and defining the basic data requirements and the flow of information between various models. These studies, which were supported by the Office of Water Resources Research, U. S. Department of Interior and the Texas Water Development Board, resulted in five different models linked through basic input-output requirements. These models were

1.	HYDTID	-	a two-dimensional vertically-mixed explicit tidal hydrodynamic model, (Refs. 4,5).
2.	STERM	-	a two-dimensional vertically-mixed implicit dynamic convective-dispersion model for analyses of short-term transport phenomena, (Ref. 7).
3.	LOTRAN	-	a two-dimensional vertically-mixed implicit dynamic convective-dispersion model for analyzing long-term or slowly varying transport phenomena, (Ref. 6).
4.	TRANSS	-	a two-dimensional vertically-mixed steady-state convective-dispersion model, (Ref. 8).
5.		-	a two-dimensional vertically-mixed explicit dynamic convective-dispersion model for analyzing long-term or slowly varying changes in salinity, (Ref. 8).

Of the three transport models, the short-term model STERM is the most fundamental and was developed to account for rapidly changing conditions such as those which occur within a tidal cycle where depths and tidal currents are continually changing. When run consecutively for an extended period of time, e.g. weeks, months or years, the model can also provide changes due to hydrologic, seasonal, or other slowly varying influences. Also, if operated under constant inputs for a long period of time, this model will converge to steady-state conditions.

This extended use of the short-term model can only be accomplished at the expense of computer time and great masses of data which then must be analyzed to determine the particular variation sought. To determine transport variations under slowly varying inputs, it is considered more practical and economical to view the transport process directly on a daily, weekly, or monthly average basis. It is for these applications that the long-term dynamic and the steady-state models were developed. Except for a series of studies on hurricane surges, comprehensive mathematical modeling for tidal hydrodynamics and water quality was not undertaken until 1970. At this time, the Texas Water Development Board (TWDB) supported a study to apply HYDTID and LOTRAN to the San Antonio and Matagorda Bays (9). In 1971 the TWDB-supported work was extended to the combined Corpus Christi and Aransas-Copano Bay systems (10). Although LOTRAN was limited to the simulation of total dissolved solids, this study made use of field data collected in a joint TWDB/U. S. Geological Survey (USGS) sampling program (11,12). Also utilized were data collected by Southwest Research Institute and Del Mar College (13). A unique feature of this TWDB study was the availability of a comprehensive data collection period where intensive measurements of tidally generated flows and water quality data were collected over a period of five days. These data provided an unusual opportunity for verification of the models.

Equally important, this same study provided for development of evaporation criteria for inclusion in the models (14). In many Texas bays and estuaries, evaporation is a very important factor and determines whether a given system is positive, negative or balanced with respect to net flows between Corpus Christi-Aransas-Copano Bays and the Gulf of Mexico.

The availability of extensive data and the existence of verified hydrodynamic and salinity models through the recent TWDB studies provided a situation ideal for further water quality modeling and to make whatever changes necessary to adapt these models to the purposes of evaluating the environmental impact of various hypothetical management policies for this region.

CHAPTER II
HYDRODYNAMIC MODEL

From consideration of the objectives of this project, it has been determined that the combined modeling capabilities represented by HYDTID and LOTRAN best serve the objectives of this project. These two models have been used extensively along the Gulf Coast (5,6,9) and both have been verified for the combined Corpus Christi-Aransas-Copano Bay system (10).

In the formulation of these two models it is assumed that the bay waters are vertically well-mixed and that the tidally generated velocities in each coordinate (area-wise) direction can be represented by corresponding vertically integrated values. According to most observed field data, complete vertical mixing is a condition which exists in the shallow Gulf Coast embayments except during period of high fresh water inflow and in some of the deeper navigation channels. The use of vertically integrated velocities is an assumption that is more difficult to assess at least for some special situations. However, many water quality responses can be analyzed with sufficient accuracy for evaluations of various policies without complete knowledge of all the tidal hydrodynamics. Furthermore, one of the main purposes of the hydrodynamic model is to obtain the flows per unit of width for input to the transport model, LOTRAN. In addition the use of tidal dispersion coefficients in LOTRAN eliminates the need to describe separately the turbulent diffusion and differential convection due to vertical velocity gradients. Therefore, these assumptions are not considered overly severe and should not hinder the utility of the models as tools for evaluating the effects of various policies or practices.

Description of HYDTID

Mathematical characterization of the hydrodynamics of a two-dimensional estuarine system requires the simultaneous solution of the dynamic equations of motion and the unsteady continuity equation. The theoretical basis for these equations have been dealt with in detail in the literature (15) and will not be repeated here.

Neglecting the convective acceleration terms but including wind stresses and the Coriolis acceleration, the equations of motion applicable to tidal flow can be written as

$$\frac{\partial q_x}{\partial t} - \Omega q_y = - g\, d\, \frac{\partial h}{\partial x} - f\, q\, q_x + K V_w^2 \cos \Psi \qquad \text{(II-1)}$$

$$\frac{\partial q_y}{\partial t} + \Omega q_x = - g\, d \frac{\partial h}{\partial y} - f\, q\, q_y + K V_w^2 \sin \Psi \qquad \text{(II-2)}$$

The equation of continuity for unsteady flow can be expressed as

$$\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial h}{\partial t} = r - e \qquad \text{(II-3)}$$

In eqs. (II-1), (II-2), and (II-3),

where q_x and q_y are the vertically integrated flows per foot of width at time t in the x and y directions, respectively (x and y taken in the plane of the surface area); h is the water surface elevation with respect to msl as datum; d is the depth of water at (x, y, t) and is equal to (h-z) where z is the distance with respect to msl measured negatively downward; $q = (q_x^2 + q_y^2)^{\frac{1}{2}}$; V_w is the wind speed at a specified elevation above the water surface; Ψ is the angle between the wind velocity vector and the x-axis; K is a non-dimensional wind stress coefficient such as that given by Roll (16); r is the rainfall rate; e is the evaporation rate; and Ω is the Coriolis parameter equal to $2\,\omega \sin \Phi$ where ω is the angular velocity of the earth taken as 0.73×10^{-4} rad/sec and Φ is the latitude. ($\Phi = 27.8^\circ$ for Corpus Christi Bay). The bed resistance coefficient, f, is computed from the Manning equation as $[gn^2/2.21\, d^{7/3}]$ where n is the Manning roughness coefficient. The Manning coefficient can be estimated either from the Strickler Formula knowing spatial and point distributions of sediments or it can be computed from comparisons of measured and computed tide and velocity histories.

Boundary Conditions

Because of the complex character of the Gulf Coast embayments, there are several different types of boundary conditions that must be described if prototype conditions are to be properly represented with a mathematical tidal hydrodynamic model. These conditions are as follows:

1. water-land boundaries;
2. partial internal boundaries;
3. fresh water inflow, diversion, and return flow boundaries; and
4. artificial ocean boundaries.

In addition to the water-land boundaries around the perimeter of a bay, other physical features within the system such as islands, spoil banks, dikes and jetties also can provide the equivalence of water-land boundaries. A necessary requirement for computation of tidal hydrodynamics adjacent to these boundaries is that the component of flow normal to the boundary be equal to zero.

Partial internal flow boundaries are associated with submerged reefs, spoil banks, pipe lines, etc. where water levels on both sides of the boundaries exceed the boundary crest elevations. To account for these situations the flow across the boundary is described in the manner analogous to that used for submerged weirs, i.e.

$$q_n = \pm C_s \, d_b \sqrt{q|h_1 - h_2|} \qquad \text{(II-4)}$$

where d_b is the depth of water over the boundary, h_1 and h_2 are water levels on the two sides of the boundary and C_s is an appropriate discharge coefficient. The sign of q_n is taken so that the flow is always directed towards the low head side of the boundary.

External inflows, diversions and return flows must be specified where appropriate along the perimeter of the embayment. These flows can be expressed quantitatively by the equation, $q_n = q_n(t)$, which allows the external flows to be introduced or withdrawn in any time dependent manner or at a constant rate over a prescribed period of time at any boundary location.

Artificial ocean boundaries must be described accurately since they represent the boundary along which the major forcing function for excitation of the tidal hydrodynamics must be applied. These boundaries are specified along an imaginary line three to six miles offshore of the embayment in the Gulf. The tidal flow corresponding to the excitation tide is computed according to the relationship

$$q_n = C\,(H_g - h) \qquad \text{(II-5)}$$

where C is an admittance coefficient taken as the speed of a gravity wave ($\sqrt{g\,d}$), H_g is the forcing function or known water surface elevation time history specified at the ocean boundary, and h is the previously computed water level at the ocean boundary. The excitation tides, H_g, are usually obtained for the prorotype from recording tide gages and are expressed mathematically by Fourier approximations.

Solution Scheme

The basic tidal hydrodynamic equations are non-linear partial differential equations in which there is a direct dependence of d and q on the values of the three unknowns, q_x, q_y and h. Even for the most ideal situations, analytical solutions of these equations are a formidable undertaking. This, compounded with complex geometry, intricate interior features and variable boundary conditions, make purely analytical approaches unsuitable for the bays under study. For these reasons, numerical schemes are utilized to obtain the solution of eqs. (II-1), (II-2) and (II-3).

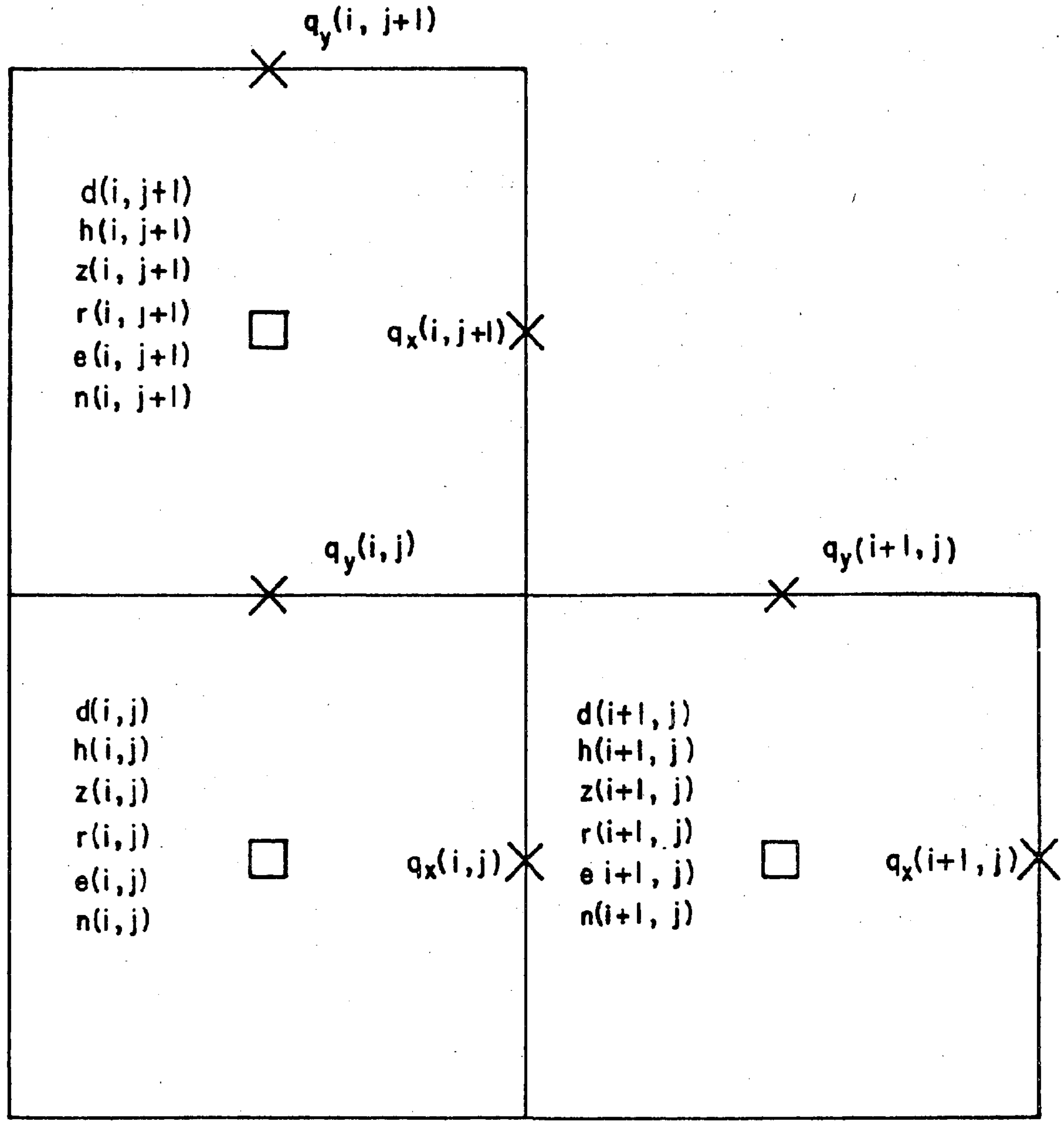
In the numerical approach, each bay is discretized into computational elements arranged in time and space so that the output from one element becomes the input to the next and so on. Each input is operated on by the transfer function for the element and through an advancing series of spatial and time steps, the functional behavior of the entire bay system is determined. The selection of these spatial and time steps is controlled by mathematical considerations involving stability, convergence and compatibility. Underlying these considerations is the further requirement that the tidal hydrodynamic and transport models effectively interface with one another so that the computed tidal amplitudes and velocities can be used directly as input to the transport models.

Basic Finite Difference Equations

The computational scheme used to solve the two equations of motion and the unsteady continuity equation involves a straight explicit formulation. In this method, eqs. (II-1), (II-2) and (II-3) are written in finite difference form and the three basic unknowns, q_x, q_y and h, are determined for each computational element at time level $(t + \Delta t)$ in terms of known conditions at time level, t. This solution scheme is similar to that used by Reid and Bodine (17) in their hurricane surge model of Galveston Bay.

Variable definitions used in the explicit formulation are illustrated on the discrete element in Figure II-1. Each element of this type is identified by the indicies, (i,j), i representing the x-direction, and j the y-direction. The indicies, i and j, increase with positive x and y respectively. In the numerical analog the discharges per unit width in the x and y directions are defined at the centers of the right and upper sides of each cell, respectively. The value of h is taken as the msl water level for the cell (i,j) and is defined at the center of the cell. Also defined at the center of each cell are the bottom elevation, the Manning roughness coefficient, rainfall rate, and evaporation rate.

FIGURE II-1
GRID SCHEME AND VARIABLE LOCATIONS FOR HYDTID



The explicit method used is a time-centered difference scheme involving time operations of the "leap frog" type for computations of flows and water levels. The following time notation is used in the recursion relations: $t-1 = (k - \frac{1}{2})\,\Delta t$; $t = (k\,\Delta t)$; $t+1 = (k+\frac{1}{2})\,\Delta t$ and $t+2 = (k+1)\,\Delta t$ where k is an interger.

To reduce computer storage, time staggered computations are made with q_x and q_y at odd $(k \pm \frac{1}{2})$ time levels and h at even (k, k+1) time levels. The wind stresses are applied at spatial locations consistent with q_x and q_y but at even time levels. The selected time differencing scheme is such that the difference $(q_x^{t+1} - q_x^{t-1})$ is centered in time at the level of h^t and the difference $(h^{t+2} - h^t)$ is centered at the time level of q_x^{t+1} or q_y^{t+1}.

Using the above notations and writing the derivatives in eqs. (II-1) to (II-3) as centered differences, the three basic unknowns, q_x, q_y and h at time (t+1) can be solved in terms of known values of time t as follows:

$$q_x^{t+1}(i,j) = \frac{1}{C_x^{t-1}} \left[q_x^{t-1}(i,j) + g\Delta t \frac{\{d^t(i,j) + d^t(i+1,j)\}}{2} \left\{ \frac{h^t(i,j)\ h^t(i+1,j)}{\Delta x} \right\} + X_w^t(i,j)\,\Delta t + \Omega\, \bar{q}_y^{\,t-1}(i,j)\Delta t \right] \tag{II-6}$$

$$q_y^{t+1}(i,j) = \frac{1}{C_y^{t-1}} \left[q_y^{t-1}(i,j) + g\Delta t \left\{ \frac{d^t(i,j) + d^t(i,j+1)}{2} \right\} \left\{ \frac{h^t(i,j) - h^t(i,j+1)}{\Delta y} \right\} + Y_w^t(i,j)\,\Delta t - \Omega\, \bar{q}_x^{\,t-1}(i,j)\Delta t \right] \tag{II-7}$$

$$h^{t+2}(i,j) = h^{t}(i,j) + \Delta t \left[\frac{q_x^{t+1}(i-1,j) - q_x^{t+1}(i,j)}{\Delta x} \right.$$

$$\left. + \frac{q_y^{t+1}(i,j-1) - q_y^{t+1}(i,j)}{\Delta y} + r^{t+1}(i,j) - e^{t+1}(i,j) \right] \qquad \text{(II-8)}$$

where

$$d(i,j) = h(i,j) - z(i,j)$$

$$\bar{q}_x(i,j) = \frac{q_x(i,j) + q_x(i,j+1) + q_x(i-1,j+1) + q_x(i-1,j)}{4}$$

$$\bar{q}_y(i,j) = \frac{q_y(i,j) + q_y(i+1,j) + q_y(i,j-1) + q_y(i+1,j-1)}{4}$$

and C_x and C_y are parameters which incorporate the effects of frictional forces and given by

$$C_x = 1+f(i,j)\Delta t \left[\left\{ q_x^{t-1}(i,j) \right\}^2 + \left\{ \bar{q}_y^{\,t-1}(i,j) \right\}^2 \right]^{\frac{1}{2}}$$

$$\left[\frac{d^t(i,j) + d^t(i+1,j)}{2} \right]^{-2} \qquad \text{(II-9)}$$

and

$$C_y = 1+f(i,j)\Delta t \left[\left\{ q_y^{t-1}(i,j) \right\}^2 + \left\{ \bar{q}_x^{\,t-1}(i,j) \right\}^2 \right]^{\frac{1}{2}}$$

$$\left[\frac{d^t(i,j) + d^t(i,j+1)}{2} \right]^{-2} \qquad \text{(II-10)}$$

The terms $\bar{q}_x(i,j)$ and $\bar{q}_y(i,j)$ have already been defined and the friction term $f(i,j)$ is given by

$$f(i,j) = \frac{g\, n^2(i,j)}{2.21 \left[\frac{d^t(i,j) + d^t(i+1,j)}{2} \right]^{1/3}} \qquad \text{(II-11)}$$

in the expression for C_x, and

$$f(i,j) = \frac{g\, n^2(i,j)}{2.21 \left[\frac{d^t(i,j) + d^t(i,j+1)}{2}\right]^{1/3}} \qquad \text{(II-12)}$$

in the expression for C_y.

Finite Difference Equations for Internal Barriers

Narrow partially submerged barriers in the system are considered along the faces of a given cell. Basically, the same finite difference equations are used except that the terms C_x and C_y incorporate the discharge coefficient in eq. (II-4) in terms of an equivalent friction factor.

For a typical submerged barrier parallel to the y-axis and positioned at the right side of cell (i,j), $q_x^{t+1}(i,j)$ is evaluated from eq. (II-6) using

$$C_x = 1 + \frac{\Delta t}{2\Delta x} \cdot \frac{[d^t(i+1,j) + d^t(i,j)]\left|q_x^{t-1}(i,j)\right|}{(C_s d_b)^2} \qquad \text{(II-13)}$$

in which

$$d_b = \tfrac{1}{2}[h^t(i+1,j) + h^t(i,j)] - z_b$$

where z_b is the barrier elevation.

Similarly for a submerged barrier parallel to the x-axis,

$$C_y = 1 + \frac{\Delta t}{2\Delta x} \cdot \frac{[d^t(i,j) + d^t(i,j+1)]\left|q_y^{t-1}(i,j)\right|}{(C_s d_b)^2} \qquad \text{(II-14)}$$

where

$$d_b = \tfrac{1}{2}[h^t(i,j) + h^t(i,j+1)] - z_b$$

The expressions for C_x and C_y are essentially of the same type used by Reid and Bodine (17).

At the ocean boundary and parallel to the x-axis of the computational grid, eq. (II-5) is used in the following difference form

$$q_y^{t+1}(i,j) = [g\, d^t(i,j)]^{\frac{1}{2}} [H_g - h^t(i,j)] \qquad \text{(II-15)}$$

in which H_g is the excitation tide at the ocean boundary. An equation identical to eq. (II-15) can be written for an ocean boundary parallel to the y-axis.

Equations (II-6) to (II-8) together with the boundary conditions in difference form, eqs. (II-13) to (II-15) are in a form amenable to computer solution.

Selection of Time Steps and Distance

As noted earlier, the element or cell size and the time step in an explicit formulation are controlled by mathematical considerations arising from stability, convergence and compatibility. Specifically the following criterion must be maintained for a stable solution of eqs. (II-6) to (II-8)

$$\Delta t \le \frac{\Delta s}{\sqrt{2 g d_{max}}} \qquad \text{(II-16)}$$

where Δt is the time step; Δs is the cell or element size; and d_{max} is the maximum water depth in the bay system. The element size is normally a function of the spatial resolution and detail required to describe the geometry and behavior of the system under various inputs. Ideally, Δs would be made as small as possible, but this can only be done at the expense of computer time and storage. Furthermore, prototype data usually are not collected with the resolution necessary to verify small cell models. The choice of element size, Δs, (Δx or Δy) therefore must be based on available prototype data, desired detail, and computer time and storage in addition to the mathematical considerations noted above.

CHAPTER III
CONSERVATIVE TRANSPORT MODEL

The transport processes of conservative constituents can be described by use of the convective-diffusion equation which is based on the principle of mass conservation. Numerous and complete derivations of this equation exist in the literature and will not be repeated here (18,19,20). The basic spatially two-dimensional form of the convective-diffusion equation in turbulent flow is

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} = \frac{\partial\left(\epsilon_x \frac{\partial c}{\partial x}\right)}{\partial x} + \frac{\partial\left(\epsilon_y \frac{\partial c}{\partial y}\right)}{\partial y} + D_m\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2}\right) \qquad \text{(III-1)}$$

where c is the concentration, u and v are temporally averaged local velocities in the x and y directions, ϵ_x and ϵ_y are turbulent diffusion coefficients in the x and y directions, and D_m is the molecular diffusion coefficient. Eq. (III-1) can be rewritten for a horizontal two-dimensional vertically well-mixed flow field using spatially averaged concentration and velocity terms and a dispersion coefficient to include convection by vertically integrated velocities, diffusion, and differential convective transport as follows

$$\frac{\partial \bar{c}}{\partial t} + \bar{u}\frac{\partial \bar{c}}{\partial x} + \bar{v}\frac{\partial \bar{c}}{\partial y} = \frac{\partial\left(D_x \frac{\partial \bar{c}}{\partial x}\right)}{\partial x} + \frac{\partial\left(D_y \frac{\partial \bar{c}}{\partial y}\right)}{\partial y} \qquad \text{(III-2)}$$

where $\bar{u} = q_x/d$ and $\bar{v} = q_y/d$, q_x and q_y are the flows per unit width in the x and y directions, D_x and D_y are the corresponding dispersion coefficients and d is the water depth.

Long-Term Analyses

For the purposes of long-term analyses the instantaneous velocities in eq. (III-2) are replaced with the net velocities that occur during a tidal period. Because tidal hydrodynamics are normally cyclic, it is possible to determine net velocity components across pre-specified sections by summing vectorally the instantaneous velocities at the sections throughout a tidal period. While the concept of a net velocity is not physically realistic, it can be determined mathematically for velocities in two directions as follows

$$U = \frac{1}{T} \int_{o}^{T} \bar{u}\,(t)\; d\,t \qquad \text{(III-3)}$$

$$V = \frac{1}{T} \int_{o}^{T} \bar{v}\,(t)\; d\,t \qquad \text{(III-4)}$$

where T is the tidal period. This temporal averaging of convective components over a tidal cycle requires further that the more conventional coefficients in eq. (III-2) be adjusted to reflect the tidal mixing which occurs throughout the total tidal period.

By substituting these quantities into eq. (III-2), the convective-dispersion equation for solution of long-term transport problems in tidal waters becomes

$$\frac{\partial c}{\partial t} + U \frac{\partial c}{\partial x} + V \frac{\partial c}{\partial x} = \frac{\partial}{\partial x} (E_x \frac{\partial c}{\partial x}) + \frac{\partial}{\partial y} (E_y \frac{\partial c}{\partial y}) \qquad \text{(III-5)}$$

where E_x and E_y are tidal dispersion coefficients.

Water Quality Considerations

A primary goal of this task force has been the development and calibration of transport models which simulate the effect of changing river inflows and wastewater discharges on the concentrations of various water quality constituents in Corpus Christi Bay. The long-term transport model, LOTRAN, applied to Corpus Christi Bay has been shown to adequately simulate the transport of non-reactive or conservative substances such as total dissolved solids (10). Other water quality constituents which behave in a reactive or non-conservative manner (participating in chemical or biological reactions) have been adequately simulated in estuarine environments by assuming they behave as single constituent first-order reactants (21).

Three additional transport models have been developed using LOTRAN, the slowly-varying mass transport model designed specifically to simulate the transport of total dissolved solids (TDS), as the basic model. The fundamental equation for mass transport has been described previously (eq. III-5). For the case of a two-dimensional, vertically-mixed bay system with reactive components, eq. (III-5) can be written as

$$\frac{\partial (C\bar{d})}{\partial t} + \frac{\partial (\bar{q}_x C)}{\partial x} + \frac{\partial (\bar{q}_y C)}{\partial y} = \frac{\partial}{\partial x}\left[E_x \bar{d} \frac{\partial C}{\partial x}\right] + \frac{\partial}{\partial y}\left[E_y \bar{d} \frac{\partial C}{\partial y}\right] \pm S_i \qquad \text{(III-6)}$$

where C is the tidally averaged concentration, $\bar{q}_x$ is the net flow per unit width over a tidal cycle in the x-direction, $\bar{q}_y$ is the net flow per unit width over a tidal cycle in the y-direction, and $\bar{d}$ is the average tidal depth over one cycle. The term, $\pm S_i$, represents various sources and sinks of the constituent for which the above equation is written, including various chemical and biological reactions. For the case in which first-order reactions are assumed to occur,

$$S_i = KC\bar{d},$$

where K is the reaction rate coefficient (1/time). Other sources and sinks are the discharges, diversions, boundaries with adjacent water bodies, and the boundary with the atmosphere where evaporation and precipitation occur.

Solution Technique

The solution technique utilized in the water quality models is the implicit alternating direction (ADI) solution method discussed by Peaceman and Rachford (22) and Douglas and Gunn (23).

The ADI method was originally formulated for the solution of heat flow equations, but as suggested by Carnahan, et al (24), the method has general application. It is unique in that it overcomes some of the difficulties of other methods identified by Peaceman and Rachford in their analysis of the solution of parabolic and elliptic differential equations in connection with solutions of two-dimensional heat flow problems. Specifically they concluded that explicit difference equations can be solved in a rather straightforward manner, but require an excessively large number of time steps limited in size by criteria for mathematical stability. Solution by purely implicit formulations, on the other hand, do not limit the time step but require a time consuming and complicated iterative solution of many sets of simultaneous equations at each time step. Gebhard and Masch (25) substantiated these findings with their analysis of the limitations and relative advantages of the explicit, implicit, and characteristic methods of solution of the convective-dispersion equation applied to inland water bodies.

The ADI method affords a direct and practical solution of the two-dimensional convective-dispersion equation by considering dependent variables in only one of the two coordinate directions to be implicit at any one given time. Through application of this technique, the resulting finite difference equations utilizing central differences produce a coefficient matrix of tridiagonal form as described by Carnahan. Such a matrix form allows direct solution of the unknowns by using an equivalent Gaussian elimination method called the Thomas Algorithm as discussed by Bruce, et al (26). By alternating the direction for implicit variables at successive intervals of half time steps, complete solutions are obtained at intervals of whole time steps. Thus by sweeping the computational matrix composed of the grid network, first row by row with unknown variables implicit in the x-direction and then column by column with unknown variables implicit in the y-direction, solution of the convective-dispersion equation over the entire array results.

The primary advantage of the ADI method, aside from possessing a high rate of convergence as illustrated by Carnahan with regard to discretization error, are that it is unconditionally stable for any value of time step, Δt, and that it does not require an impractical iterative solution method. Stability implies that there is an upper limit as $\Delta t \rightarrow 0$ to which any information, whether input as initial or boundary conditions or computed in the solution process, can be amplified and Carnahan proved the state of unconditional stability for the ADI method by showing $|\xi| < 1$. The condition $\Delta t/\overline{\Delta s}^{\,2} < \frac{1}{2}$ should be maintained to minimize round-off and truncation errors; however, this condition is easily satisfied when values typical of present day models are used in the relation.

A more detailed description of the ADI method and its application to the convective-dispersion equation is presented in the next section. Its actual use can better be understood by writing eq. (III-5) in finite difference form and constructing the computational matrices of coefficients and unknowns which result after substituting and rearranging terms.

Application of the ADI solution scheme to the basic two-dimensional convective-dispersion equation, eq. (III-5) requires, first, writing the equation in finite difference form for the two different cases of implicit variables. Secondly, the difference equations must be rearranged and appropriate substitutions made to structure them in a form amenable to solution by the

Thomas Algorithm, and finally, the sets of difference equations must be incorporated into a control program to facilitate the computational process and data input-output procedures.

An important part of rewriting eq. (III-5) in finite difference form is the definition of the variable locations with respect to individual grid elements. Care must be taken to position the variables, particularly velocities, dispersion coefficients, and concentrations, in a manner that is consistent with the finite difference requirements of derivatives in the eq. (III-5). Also, consideration must be given to the variable assignment scheme employed by the hydrodynamic model to assure compatibility between the two models with regard to velocity locations. Figure III-1 illustrates the locations of the significant variables used in the model, HYDTID. Only average tidal depth, $\bar{d}$, defined at the center of the cell and the flows per unit width, $\bar{q}_x$ and $\bar{q}_y$, defined across the sides of the cell are of significance to the transport modeling. Utilizing the same grid scheme as in the hydrodynamic model, the location of the pertinent variables required by the transport model are shown in Figure III-1. With this space-staggered arrangement it is possible to take full advantage of variable locations not only in formulating finite difference equations but also in developing an efficient program structure for implementation of the ADI solution method.

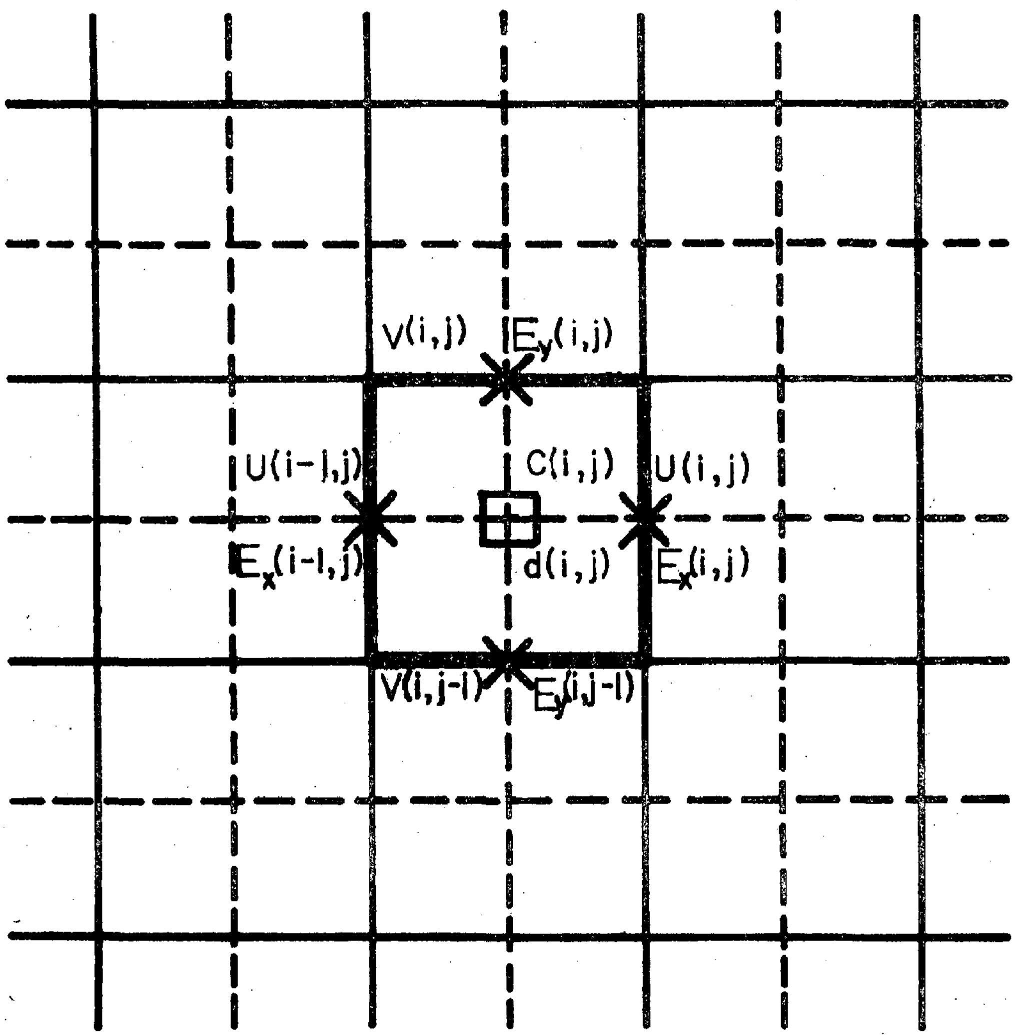
Finite Difference Approximations

The basic equation applicable to the tidally influenced slowly-varying transport problems of interest in this study is given by eq. (III-5). As an example, assuming no sources and sinks, the convective-dispersion equation for the transport of a conservative substance B is presented as follows

$$\frac{\partial(B)}{\partial t} + \frac{\partial(UB)}{\partial x} + \frac{\partial(VB)}{\partial y} = \frac{\partial}{\partial x}\left[E_x \frac{\partial(B)}{\partial x}\right] + \frac{\partial}{\partial y}\left[E_y \frac{\partial(B)}{\partial y}\right] \qquad \text{(III-7)}$$

The ADI solution method requires writing two different sets of finite difference equations both formulated from eq. (III-7), but at different time levels. The first set, written for time level (t+1), approximates x-derivatives involving unknown concentration implicitly and y-derivatives explicitly; while the second set, written for time level (t+2), reverses the procedure and uses implicit y-derivative approximations and explicit x-derivatives. To illustrate the development of these expressions consider the following difference forms of the individual terms in eq. (III-7) at time level (t+1) when all quantities are

FIGURE III-1
GRID SCHEME AND VARIABLE LOCATIONS USED
IN LONG-TERM TRANSPORT MODEL



known at time t,

$$\frac{\partial B}{\partial t} = \frac{B^{t+1}(i,j) - B^{t}(i,j)}{\Delta t} \qquad \text{(III-8)}$$

$$\frac{\partial (E_x \frac{\partial B}{\partial x})}{\partial x} = E_x(i,j)\,\frac{[B^{t+1}(i+1,j) - B^{t+1}(i,j)]}{\Delta x^2} - E_x(i-1,j)\,\frac{[B^{t+1}(i,j) - B^{t+1}(i-1,j)]}{\Delta x^2} \qquad \text{(III-9)}$$

$$\frac{\partial (E_y \frac{\partial B}{\partial y})}{\partial y} = E_y(i,j)\,\frac{[B^{t}(i,j+1) - B^{t}(i,j)]}{\Delta y^2} - E_y(i,j-1)\,\frac{[B^{t}(i,j) - B^{t}(i,j-1)]}{\Delta y^2} \qquad \text{(III-10)}$$

$$\frac{\partial (UB)}{\partial x} = U(i,j)\,\frac{[B^{t+1}(i+1,j) + B^{t+1}(i,j)]}{2\Delta x} - U(i-1,j)\,\frac{[B^{t+1}(i,j) + B^{t+1}(i-1,j)]}{2\Delta x} \qquad \text{(III-11)}$$

$$\frac{\partial (VB)}{\partial y} = V(i,j)\,\frac{[B^{t}(i,j+1) + B^{t}(i,j)]}{2\Delta y} - B(i,j-1)\,\frac{[B^{t}(i,j) + B^{t}(i,j-1)]}{2\Delta y} \qquad \text{(III-12)}$$

Similarly these same terms can be approximated at time level (t+2) utilizing known conditions from time (t+1) as follows,

$$\frac{\partial B}{\partial t} = \frac{B^{t+2}(i,j) - B^{t+1}(i,j)}{\Delta t} \tag{III-13}$$

$$\frac{\partial (E_x \frac{\partial B}{\partial x})}{\partial x} = E_x(i,j)\,\frac{[B^{t+1}(i+1,j) - B^{t+1}(i,j)]}{\Delta x^2} - E_x(i-1,j)\,\frac{[B^{t+1}(i,j) - B^{t+1}(i-1,j)]}{\Delta x^2} \tag{III-14}$$

$$\frac{\partial (E_y \frac{\partial B}{\partial y})}{\partial y} = E_y(i,j)\,\frac{[B^{t+2}(i,j+1) - B^{t+1}(i,j)]}{\Delta y^2} - E_y(i,j-1)\,\frac{[B^{t+2}(i,j) - B^{t+2}(i,j-1)]}{\Delta y^2} \tag{III-15}$$

$$\frac{\partial (UB)}{\partial x} = U(i,j)\,\frac{[B^{t+1}(i+1,j) + B^{t+1}(i,j)]}{2\Delta x} - U(i-1,j)\,\frac{[B^{t+1}(i,j) + B^{t+1}(i-1,j)]}{2\Delta x} \tag{III-16}$$

$$\frac{\partial (VB)}{\partial y} = V(i,j)\,\frac{[B^{t+2}(i,j+1) + B^{t+2}(i,j)]}{2\Delta y} - V(i,j-1)\,\frac{[B^{t+2}(i,j) + B^{t+2}(i,j-1)]}{2\Delta y} \tag{III-17}$$

Substituting the finite difference approximations of eqs. (III-8) to (III-17) into eq. (III-7) and factoring out common values of the concentrations, the following equation can be formulated to approximate implicitly in the x-direction the basic convective-dispersion equation,

$$
\begin{aligned}
&B^{t+1}(i-1,j)\left[-E_x(i-1,j)\left(\frac{\Delta t}{\Delta x^2}\right) - U(i-1,j)\left(\frac{\Delta t}{2\Delta x}\right)\right] + \\
&B^{t+1}(i,j)\left[1 + E_x(i,j)\left(\frac{\Delta t}{\Delta x^2}\right) + E_x(i-1,j)\left(\frac{\Delta t}{\Delta x^2}\right)\right. \\
&\qquad \left. - U(i-1,j)\left(\frac{\Delta t}{2\Delta x}\right) + U(i,j)\left(\frac{\Delta t}{2\Delta x}\right)\right] + \\
&B^{t+1}(i+1,j)\left[-E(i,j)\left(\frac{\Delta t}{\Delta x^2}\right) + U(i,j)\left(\frac{\Delta t}{2\Delta x}\right)\right] = \\
&B^{t}(i,j-1)\left[E_y(i,j-1)\left(\frac{\Delta t}{\Delta y^2}\right) + V(i,j-1)\left(\frac{\Delta t}{2\Delta y}\right)\right] + \\
&B^{t}(i,j)\left[1 - E_y(i,j)\left(\frac{\Delta t}{\Delta y^2}\right) - E_y(i,j-1)\left(\frac{\Delta t}{\Delta y^2}\right)\right. \\
&\qquad \left. + V(i,j-1)\left(\frac{\Delta t}{2\Delta y}\right) - V(i,j)\left(\frac{\Delta t}{2\Delta y}\right)\right] + \\
&B^{t}(i,j+1)\left[E_y(i,j)\left(\frac{\Delta t}{\Delta y^2}\right) - V(i,j)\left(\frac{\Delta t}{2\Delta y}\right)\right] \qquad \text{(III-18)}
\end{aligned}
$$

Through a similar process, eq. (III-7) also can be structured implicitly in the y-direction as

$$B^{t+2}(i,j-1)\left[-E_y(i,j-1)\left(\frac{\Delta t}{\Delta y^2}\right) - V^{t+1}(i,j-1)\left(\frac{\Delta t}{2\Delta y}\right)\right] +$$

$$B^{t+2}(i,j)\left[1 + E_y(i,j)\left(\frac{\Delta t}{\Delta y^2}\right) + E_y(i,j-1)\left(\frac{\Delta t}{\Delta y^2}\right)\right.$$

$$\left. + V(i,j)\left(\frac{\Delta t}{2\Delta y}\right) - V(i,j-1)\left(\frac{\Delta t}{2\Delta y}\right)\right] +$$

$$B^{t+2}(i,j+1)\left[V(i,j)\left(\frac{\Delta t}{2\Delta y}\right) - E_y(i,j)\left(\frac{\Delta t}{\Delta y^2}\right)\right] =$$

$$B^{t+1}(i,j-1)\left[E_x(i-1,j)\left(\frac{\Delta t}{\Delta x^2}\right) + U(i-1,j)\left(\frac{\Delta t}{2\Delta x}\right)\right] +$$

$$B^{t+1}(i,j)\left[1 - E_x(i,j)\left(\frac{\Delta t}{\Delta x^2}\right) - E_x(i-1,j)\left(\frac{\Delta t}{\Delta x^2}\right)\right.$$

$$\left. + U(i-1,j)\left(\frac{\Delta t}{2\Delta x}\right) - U(i,j)\left(\frac{\Delta t}{2\Delta x}\right)\right] +$$

$$B^{t+1}(i+1,j)\left[E_x(i,j)\left(\frac{\Delta t}{\Delta x^2}\right) - U(i,j)\left(\frac{\Delta t}{2\Delta x}\right)\right] \qquad \text{(III-19)}$$

Computational Process

Analysis of eqs. (III-18) and (III-19) indicates that all quantities on the right hand side of the equations are known and thus can be grouped into single valued terms called s. On the left hand side of the equations, all of the concentrations are unknown while the coefficients on these unknown concentrations a, b, and c, can be computed from the known values of net velocities and dispersion coefficients. At each time step and for each row or column of N adjacent water cells, depending on whether eq. (III-18) or (III-19), respectively, is applicable, N linear simultaneous equations with N unknowns can be written in algebraic form. For the case of implicit derivatives in the x-direction, the following set of equations results,

$$\begin{aligned} b_1 B_1^{t+1} + c_1 B_2^{t+1} &= s_1^t \\ a_\gamma B_{\gamma-1}^{t+1} + b_\gamma B_\gamma^{t+1} + B_\gamma B_{\gamma+1}^{t+1} &= s_\gamma^t ; \; 2 \le \gamma \le N-1 \\ a_N B_{N-1}^{t+1} + b_N B_N^{t+1} &= s_N^t \end{aligned} \tag{III-20}$$

A similar set of equations can be written for the condition of implicit y-direction derivatives. Grouping the coefficients, unknown coefficients, and known quantities in eq (III-20) into matrices $\bar{K}$, $\bar{B}$, and $\bar{S}$, respectively, the final solution matrix takes the following form,

$$\bar{K} \times \bar{B} = \bar{S} \tag{III-21}$$

or expanded,

$$
\begin{bmatrix}
b_1 & c_1 & & & & & \\
a_2 & b_2 & c_2 & & & & \\
 & a_3 & b_3 & c_3 & & & \\
 & & - & - & - & & \\
 & & & - & - & - & \\
 & & & & - & - & - \\
 & & & & & a_N & b_N
\end{bmatrix}
\begin{bmatrix}
B_1^{t+1} \\ B_2^{t+1} \\ B_3^{t+1} \\ - \\ - \\ - \\ B_N^{t+1}
\end{bmatrix}
=
\begin{bmatrix}
s_1^t \\ s_2^t \\ s_3^t \\ - \\ - \\ - \\ s_N^t
\end{bmatrix}
\quad \text{(III-22)}
$$

As a result of the coefficient matrix being of tridiagonal form, the Thomas Algorithm referred to earlier is well suited for solution of the set of equations given by eq. (III-20). Following is a detailed outline of this solution technique as used in the transport model.

(1) Divide through the first equation in eq. (III-20) by b_1 to obtain

$$B_1^{t+1} + d_1 B_2^{t+1} = g_1 \quad \text{(III-23)}$$

where

$$d_1 = \frac{B_1}{b_1} \quad \text{and} \quad g_1 = \frac{s_1^t}{b_1}$$

(2) Combine eq. (III-23) and the second equation in eq. (III-20) to eliminate a_2 which results in

$$B_2^{t+1} + d_2 B_3^{t+1} = g_2 \quad \text{(III-24)}$$

where

$$d_2 = \frac{B_2}{b_2 - a_2 d_1} \quad \text{and} \quad g_2 = \frac{s_2 - a_2 g_1}{w_2}$$

and

$$w_2 = b_2 - a_2 d_1$$

(3) Combine eq. (III-24) and the third equation in eq. (III-20) to eliminate a_3 which results in

$$B_3^{t+1} + d_3 B_4^{t+1} = g_3 \qquad \text{(III-25)}$$

where

$$d_3 = \frac{B_3}{w_3}, \quad w_3 = b_3 - a_3 d_2$$

and

$$g_3 = \frac{s_3 - a_3 g_2}{w_3}$$

(4) Proceed through the set of equations in this manner, eliminating a and storing the values of d_γ and g_γ given by

$$d_\gamma = \frac{B_\gamma}{b_\gamma - a_\gamma d_{\gamma-1}} \qquad \gamma = 2,3,\ldots,N$$

and

$$g_\gamma = \frac{s_\gamma - a_\gamma g_{\gamma-1}}{b_\gamma - a_\gamma d_{\gamma-1}} \qquad \gamma = 2,3,\ldots,N$$

(5) Solve the last equation in eq. (III-20) using

$$B_N^{t+1} = g_N \qquad \text{(III-26)}$$

(6) Solve for B_{N-1}^{t+1}, B_{N-2}^{t+2} . . . . B_1^{t+1} by back substitution with the following equation.

$$B_\gamma^{t+1} = g_\gamma - d_\gamma B_{\gamma+1}^{t+1} \qquad 1 \leq \gamma \leq N-1 \qquad \text{(III-27)}$$

In the above equations, w, d, and g are computed in order of increasing γ, and B^{t+1} is computed in order of decreasing γ. Using this computational algorithm for both x and y directions and the rectangular computational grid to represent the tidally influenced bay system distribution of constituent concentrations can be obtained by solving for B^{t+1} and B^{t+2} spatially from cell to cell first by rows and then by columns, respectively. Then by stepping forward in time and repeating the process under a new set of boundary conditions, the complete solution can progress until the desired period has been simulated.

Boundary Conditions

As with the tiday hydrodynamics model there is needed to represent boundary conditions in difference form in the transport model to reflect the convective and dispersive transport components across the boundaries of the grid network. The boundary condition across a water-land interface requires there be no convection or dispersion normal to the boundary. The no convection requirement is automatically handled by the no flow condition computed from the tidal hydrodynamics. The no dispersion condition can be achieved in the x-direction, for example, either by setting $B_{i+1,j}$, the concentration in the cell immediately across from an impermeable barrier, equal to $B_{i,j}$, the concentration in the cell of interest adjacent to the barrier (the image concept), expanding the x-derivative in a Taylor series, or by setting $E_{x(i,j)} = 0$. For simplicity in this study, the dispersion coefficients at impermeable boundaries are set equal to zero whenever velocities and the resulting convection are zero.

The conditions across an impermeable internal boundary such as a reef or island are identical with water-land boundaries except that there may be water on both sides of the barrier. Again, the requirement of no convective transport is satisfied through the hydrodynamic model while the condition of no dispersion is satisfied by setting the dispersion coefficient across the boundary equal to zero.

Source concentration boundaries represent the major excitation to the transport model and must be specified at the Gulf inlets and at all inflow, diversion, and return flow points. These sources are quantified either by direct prototype measurements or with values derived from statistical analyses of historical records. Also it is possible to extend the river reaches of the model upstream to a point where zero or some base concentration can be assumed. This same concept can be applied to the ocean boundary of the model by specifying the normal ocean concentration of a particular material offshore far enough to avoid interaction with inland sources. For example an average value of salinity could be taken as 35 parts per thousand and specified as a constant source along the seaward boundary of the model.

Initial Conditions

The initial conditions for the transport model can be either an assumed distribution of concentration or simply a constant value of concentration specified throughout the bay except at the excitation or source cells. If the solution sought is to be steady-state, the initial condition is a matter of choice since the steady-state concentration profiles are essentially independent of the initial conditions. However, if the model is to be operated for an actual or prescribed set of inputs, the model first must be run to simulate the antecedant condition and then operated consecutively on a weekly, monthly, seasonal or other basis for the period of interest. If a point release of material is to be routed through an estuary, either zero or an appropriate background concentration must be specified.

Selection of Distance and Time Steps

Since the ADI scheme is unconditionally stable, there are no mathematical restrictions on Δt and Δs for solution of eq. (III-7). The mest size, Δs, must be the same as that used in the tidal computations with the hydrodynamic model. In selecting the mesh size consideration must be given to the physical resolution desired in both the hydrodynamic and the transport models. Usually channels and tidal passes dictate the use of fairly small mesh widths in order to properly describe tidal exchange. However, such spatial resolution can only be achieved at the expense of increased computer time and storage requirements, which in the end often are the controlling factors. This is particularly important with regard to the hydrodynamic model which is restricted by mathematical stability criterion because of its explicit solution technique. For estuaries typical of the Gulf Coast, mesh sizes on the order of a square mile have proven to be economical and still fine enough to provide adequate resolution for simulation of transport behavior.

Time steps used in the transport model must only be small enough to accurately describe the temporal variations in concentrations that might occur. As has been previously stated, time steps larger than one tidal cycle might be ficticious since the net velocities used in the model are computed over a one cycle period and theoretically can only influence the transport behavior of an estuary during the actual time when they were determined. However, when fresh water inflows and tidal conditions remain fairly stable for a period of several weeks, net velocities are also likely to vary only slightly, and time steps larger than one cycle can be used. The time step used most frequently is one half of a tidal cycle.

CHAPTER IV
WATER QUALITY
TRANSPORT MODELS FOR THE
CORPUS CHRISTI BAY SYSTEM

The purpose of this chapter is to describe the development and testing of the non-conservative water quality transport models for the Corpus Christi Bay system. A review first is presented of the operation and verification of the hydrodynamic and non-conservative transport models. Next, an explanation is given of how the TWDB/USGS field data is grouped into Data Packages and evaluated for use in the non-conservative water quality transport model development. Subsequently, the equations are presented which represent the biological and chemical reactions that these water quality characteristics undergo. Finally, comparisons are made between the observed and predicted non-conservative water quality constituents.

The overall objective of the project was to develop and test a methodology to assess the environmental impact of various hypothetical coastal zone management for the Coastal Bend COG. The non-conservative water quality constituents of primary interest were BOD_5, dissolved, total phosphorus and nitrogen.

Review of Hydrodynamic and Conservative Transport Models

The Corpus Christi-Aransas-Copano Bays System Model developed by Masch and Brandes for the TWDB (10) was modified at the outset of the study to produce a smaller model with capability to include more inputs and more resolution if necessary and to facilitate the development of additional water quality models specifically for the Corpus Christi Bay environs. Modifications to the TWDB hydrodynamic and conservative transport models consisted of a reduction in size of the area modeled, adding diversions and discharges unaccounted for previously, and adjusting excitation tides at the new boundaries to correct for apparent datum discrepancies (1). The Corpus Christi Bay System Model intended for use in this project includes Corpus Christi, Nueces, Oso and Redfish Bays and the portion of Aransas Bay from Redfish Bay eastward to the Rockport tide gage. Figure IV-1 illustrates the area covered by these models.

The main problem in reducing the coverage of the original TWDB models was to develop the boundary conditions at the Rockport boundary of the models so that the Corpus Christi Bay System Model would properly simulate the hydrodynamics and transport across this section. Rockport was selected as the eastern boundary of the model because tide gage records and water quality data are available at this location. This has the advantage of being able to excite the models with actual field data rather than with simulated conditions (1).

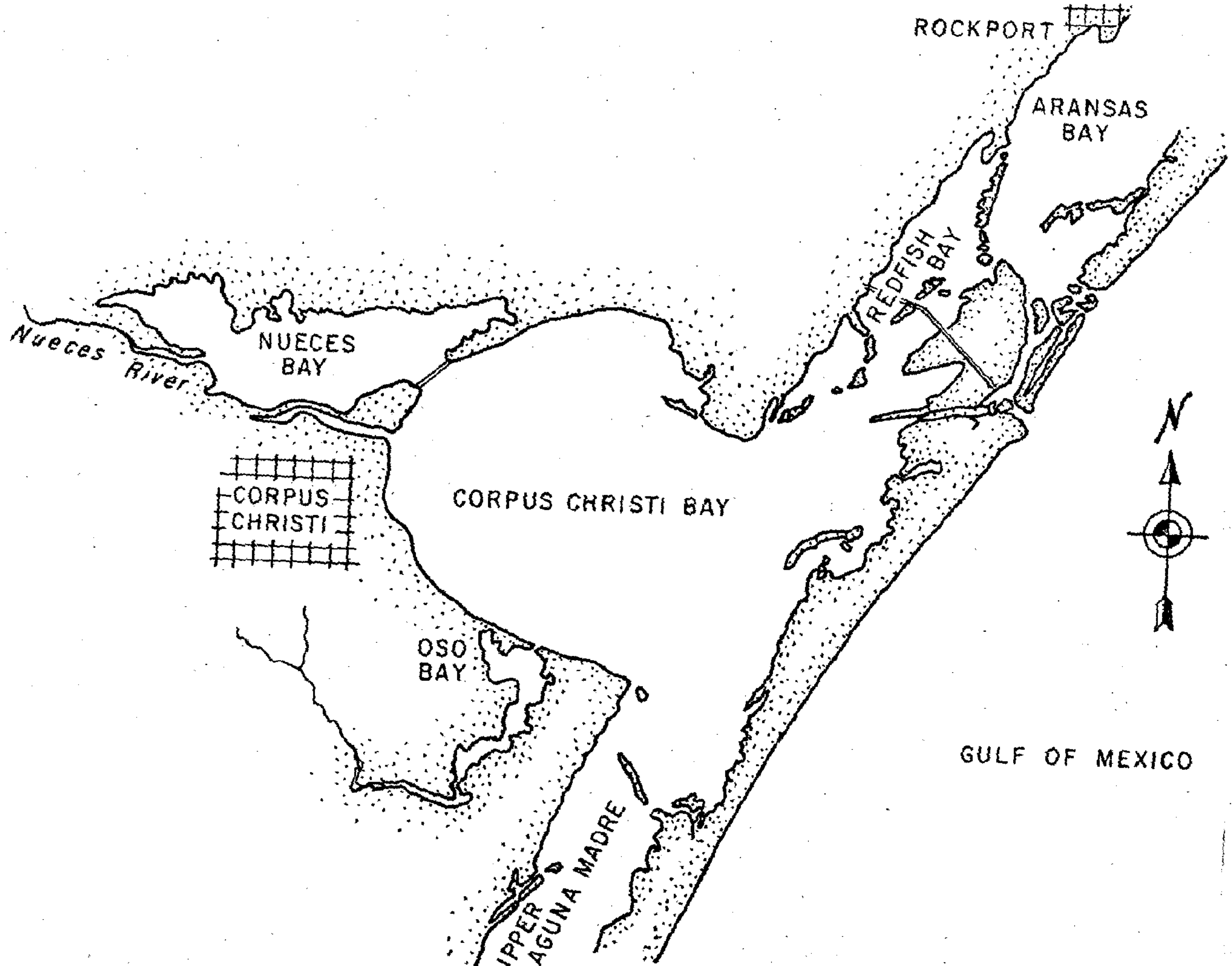


FIGURE IV-1
THE CORPUS CHRISTI BAY SYSTEM

The reduction in model size will allow additional model resolution if deemed necessary in the future. Currently, the size of the individual computational cells, which in total form the grid scheme depicted in Figure IV-2 is one nautical mile square. With the newly developed models, the resolution and/or computer storage can be increased by approximately thirty percent without increasing computer expenses now used in the TWDB models.

Preliminary to the operation of the conservative transport model, the "net" tidal amplitudes and component tidal flows are computed using the hydrodynamic model. The basic data necessary for the simulations utilized in this study are as follows for the hydrodynamic model:

(1) gulf excitation tides;
(2) excitation tides at the Upper Laguna Madre and Aransas Bay interfaces;
(3) fresh water inflows;
(4) diversions;
(5) waste discharges;
(6) wind magnitude, direction and duration;
(7) evaporation; and
(8) precipitation

Measured tidal depths at various locations in the Corpus Christi Bay system (see Figure IV-3 and Table IV-1) at different seasons over a few years period were available to "calibrate" and "verify" the hydrodynamic model. In addition, one set of tidal exchange measurements were available in November, 1971 over a tidal cycle at ten selected locations where the physiography permitted these TWDB/USGS observations.

TABLE IV-1
TIDE GAGE LOCATIONS FOR CORPUS CHRISTI BAY SYSTEM MODEL

GAGE IDENTIFICATION	CELL NUMBER	LOCATION
A	I 19J7	Aransas Pass at Port Aransas
B	I 1J10	Laguna Madre near Flour Bluff
C	I29J12	Aransas Bay near Rockport
D	I 5J18	Corpus Christi Bay at 4600 Ocean Dr.
E	I 9J26	Nueces Bay near White's Point
F	I 8J22	Corpus Christi Bay at Corpus Christi
G	I14J13	Corpus Christi Bay at Ingleside

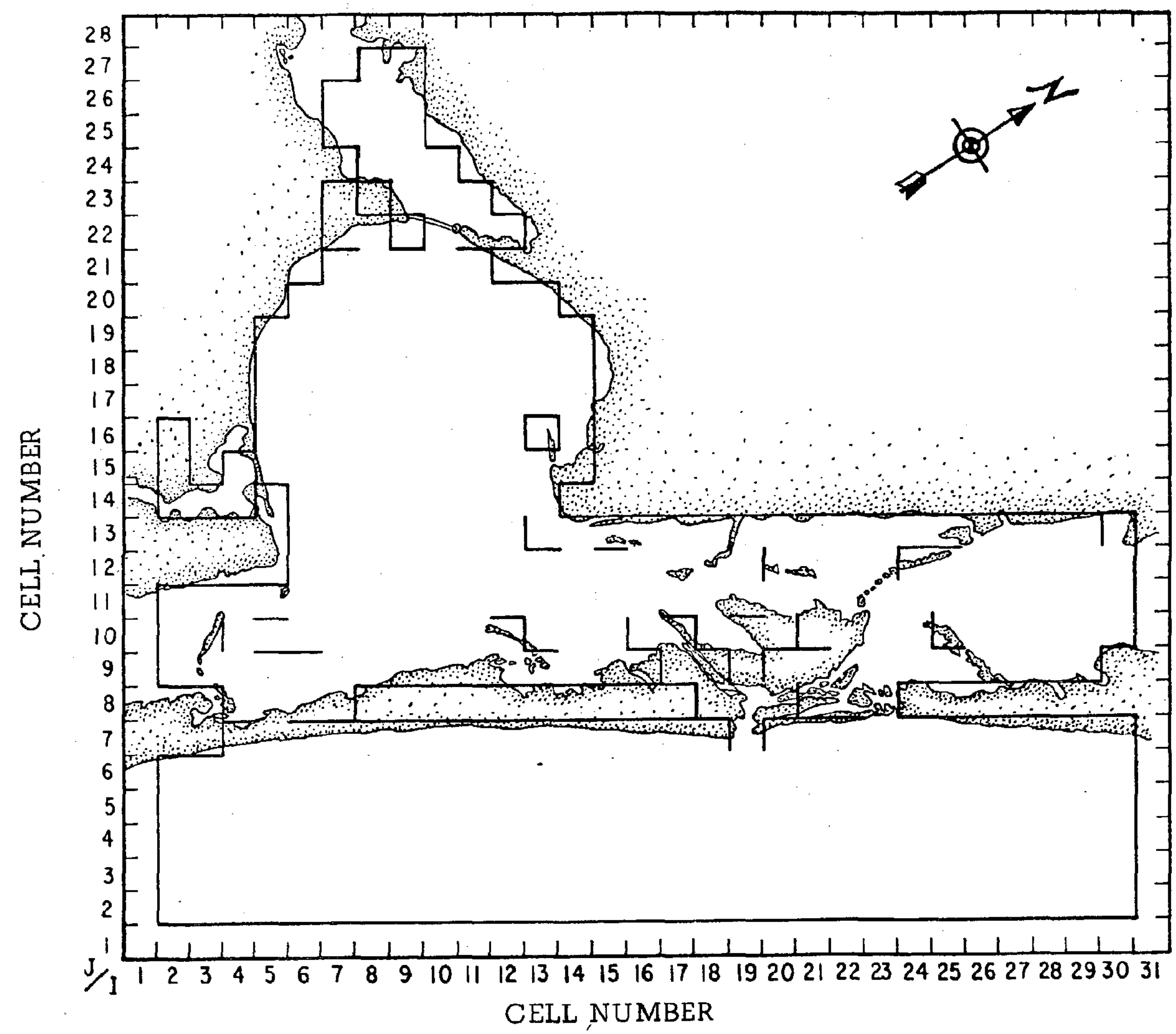


FIGURE IV-2
GRID SCHEME

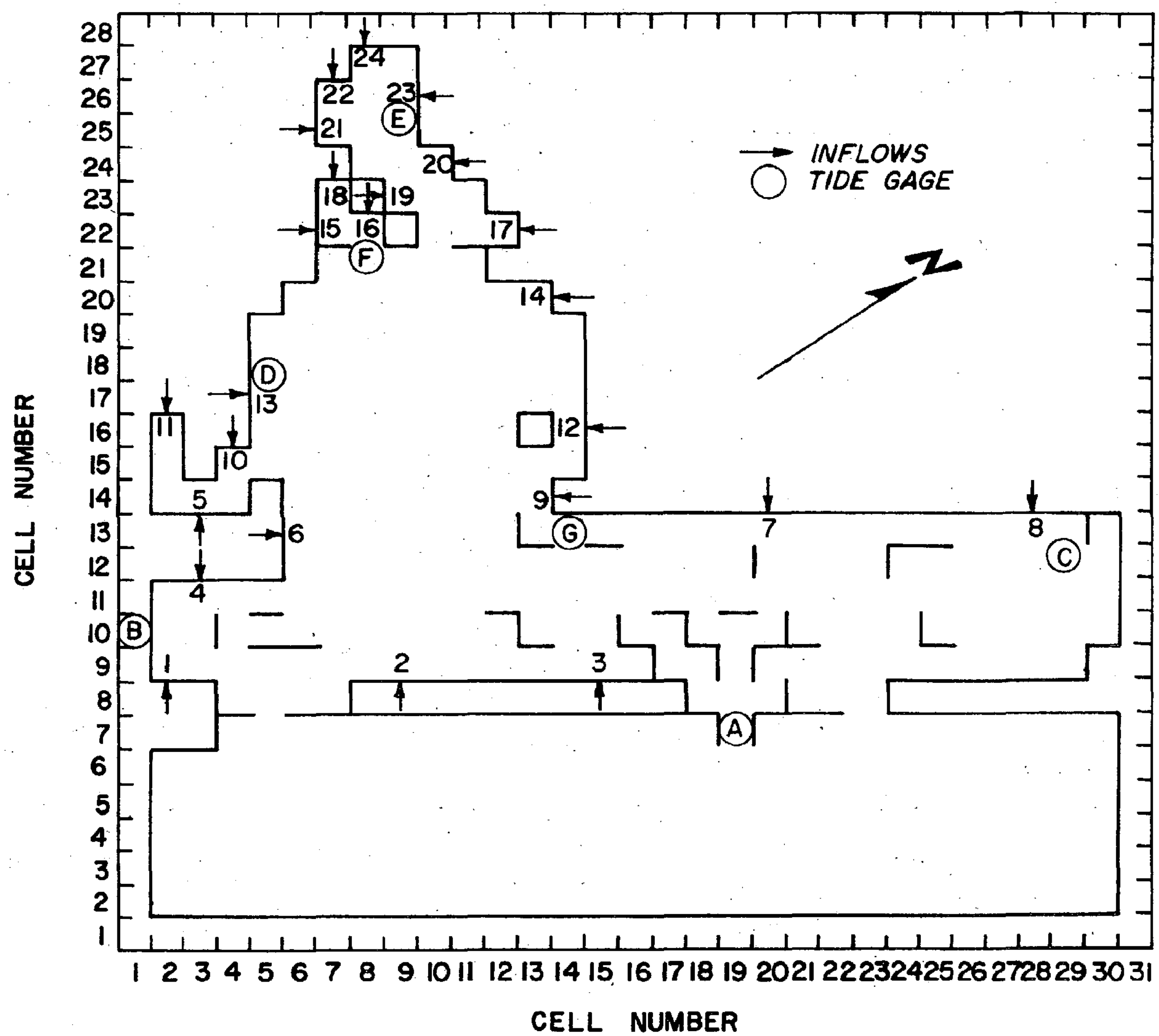


FIGURE IV-3
LOCATION OF INFLOWS AND EXISTING TIDE GAGES

The loadings of importance in the operation of HYDTID are all of the external inputs (including all discharges and fresh water inflows) and the diversions and subsequent discharges which are internal (mainly cooling water). Many of these flows represent an aggregation of flows due to the limitation that each cell is one nautical mile square. The location of the inflows are denoted by inflow number in Figure IV-3. The non-point source boundary conditions for HYDTID consist of the tidal excitations at the interfaces between the Corpus Christi Bay System and the Gulf, Upper Laguna Madre, and Aransas Bay. The selection of the Gulf excitation tide is the most crucial. It is based on the average amplitude, high and low tides taken for each tidal cycle over the total time period being simulated. Based on these average values, a tidal cycle specific tide is selected. After selection of the Gulf excitation tide is made, the Laguna Madre and Aransas Bay tides are read from the charts for the same tidal cycle. Table IV-1 identifies the tide gages as to location in the prototype and in the model grid scheme. Given representative loadings, meteorological parameters, and excitation tides, HYDTID is run to stability and the net flows and depths over one tidal cycle are computed to be used as the hydrodynamic input for the transport models.

After preliminary studies with the Corpus Christi Bay System Model, it was obvious that the hydrodynamics of the system could not be properly simulated without some adjustment of the excitation tides at the Laguna Madre and Rockport boundaries. These tidal datum adjustments are necessary due to suspected datum irregularities for some of the tide gages in the Corpus Christi Bay System. Similar difficulties have been previously reported for other estuaries (9). For example, the observed tides at the boundaries together with the adjusted tides used in the model for Data Package XVIII (see subsequent section for description) are presented in Figure IV-4. No phase corrections are necessary for any of the excitation tides. The Gulf excitation tide was held constant while the Laguna Madre excitation tide was shifted vertically downward by 0.26 feet and the Rockport excitation tide was shifted downward by 0.13 feet. This adjustment resulted in reasonable responses of tidally generated flows and net exchange being produced by the model when compared to the measured field data previously discussed. In addition, a sensitivity analysis of the hydrodynamic model testing the effects of variations in the wind stress coefficient, Manning's roughness coefficient, and the evaporation coefficient for the November 1971 data package gave added confidence in the model (1). [See the Appendix for a presentation of these results.] Hence, the hydrodynamic model is considered verified.

For the salinity transport model, the following data are required:

(1) salinity concentrations at the Gulf, Upper Laguna Madre, and Aransas Bay boundaries;
(2) salinity concentrations associated with all diversions and discharges;

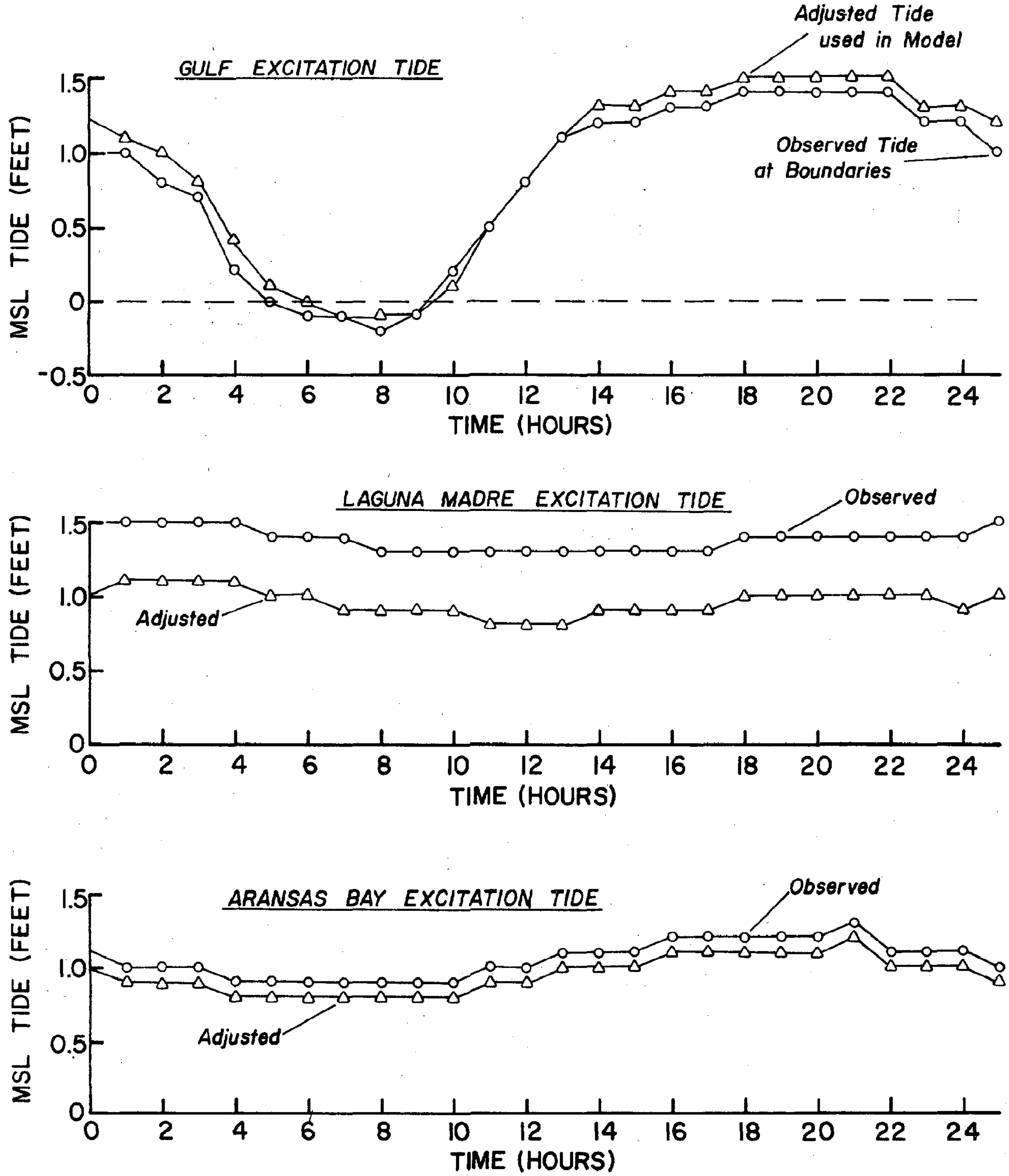


FIGURE IV-4A
OBSERVED AND ADJUSTED TIDES AT THE MODEL'S
BOUNDARIES FOR DATA PACKAGE XIV

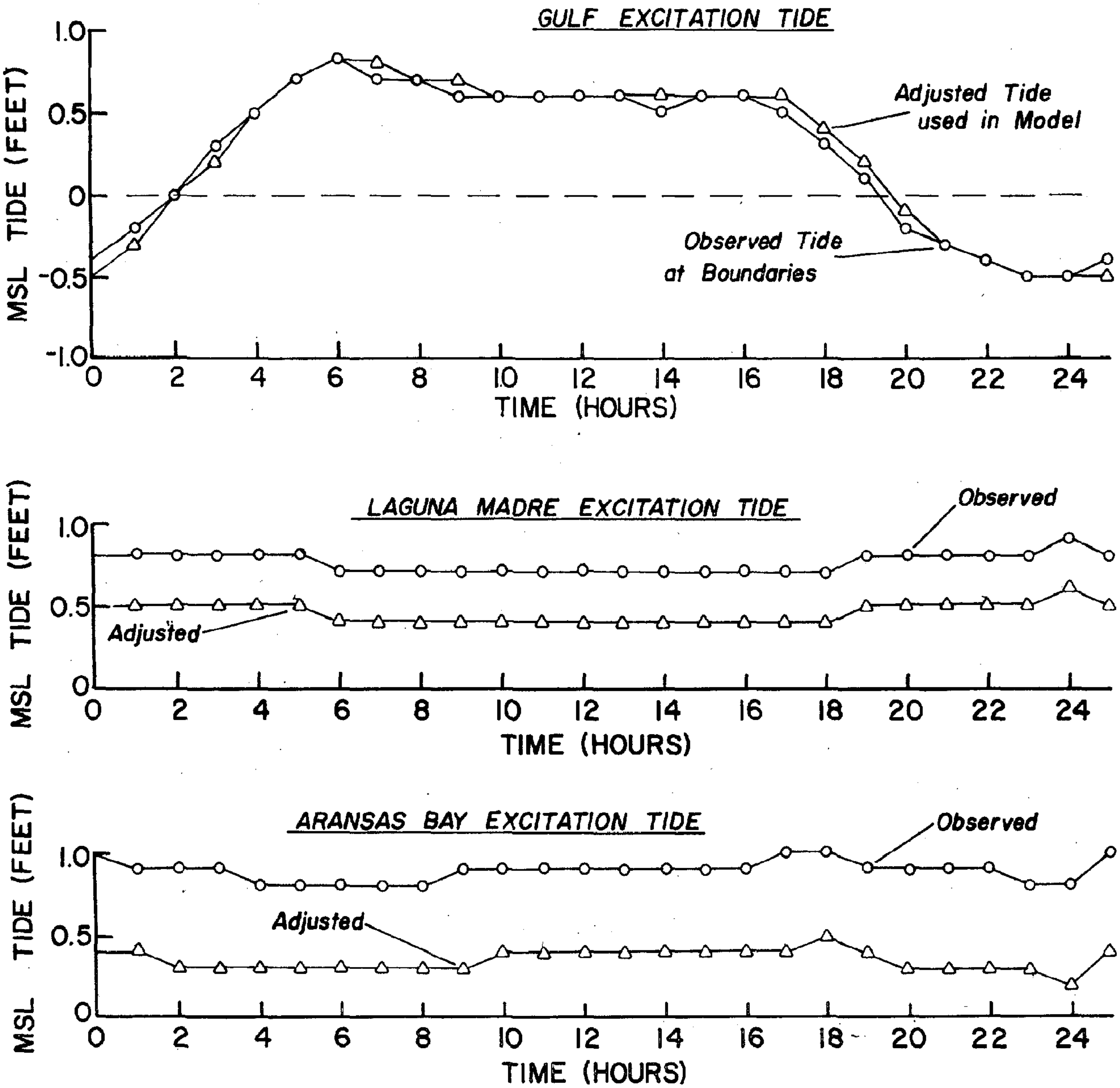


FIGURE IV-4B
OBSERVED AND ADJUSTED TIDES AT THE MODEL'S
BOUNDARIES FOR DATA PACKAGE XV

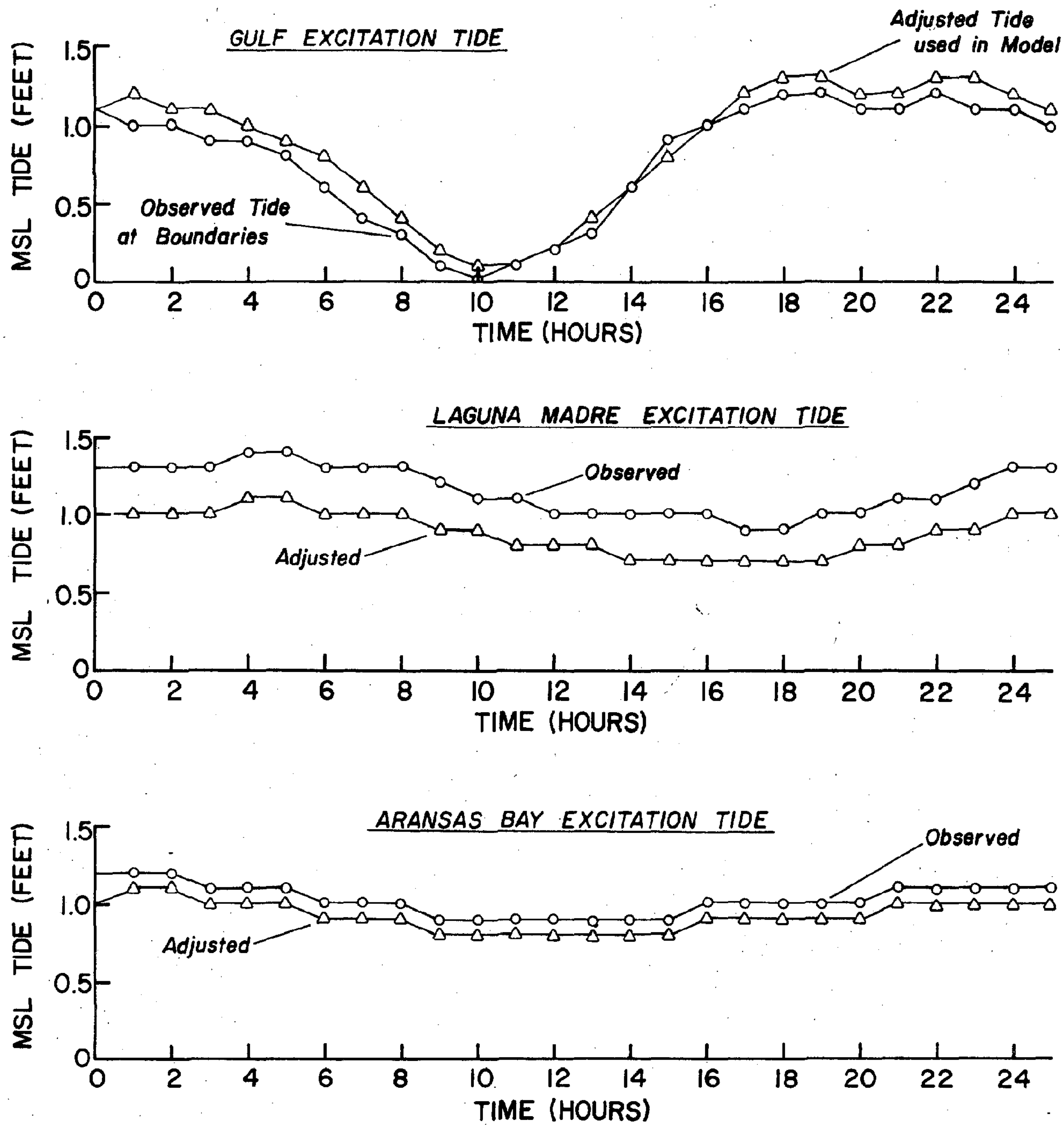


FIGURE IV-4C
OBSERVED AND ADJUSTED TIDES AT THE MODEL'S
BOUNDARIES FOR DATA PACKAGE XVIII

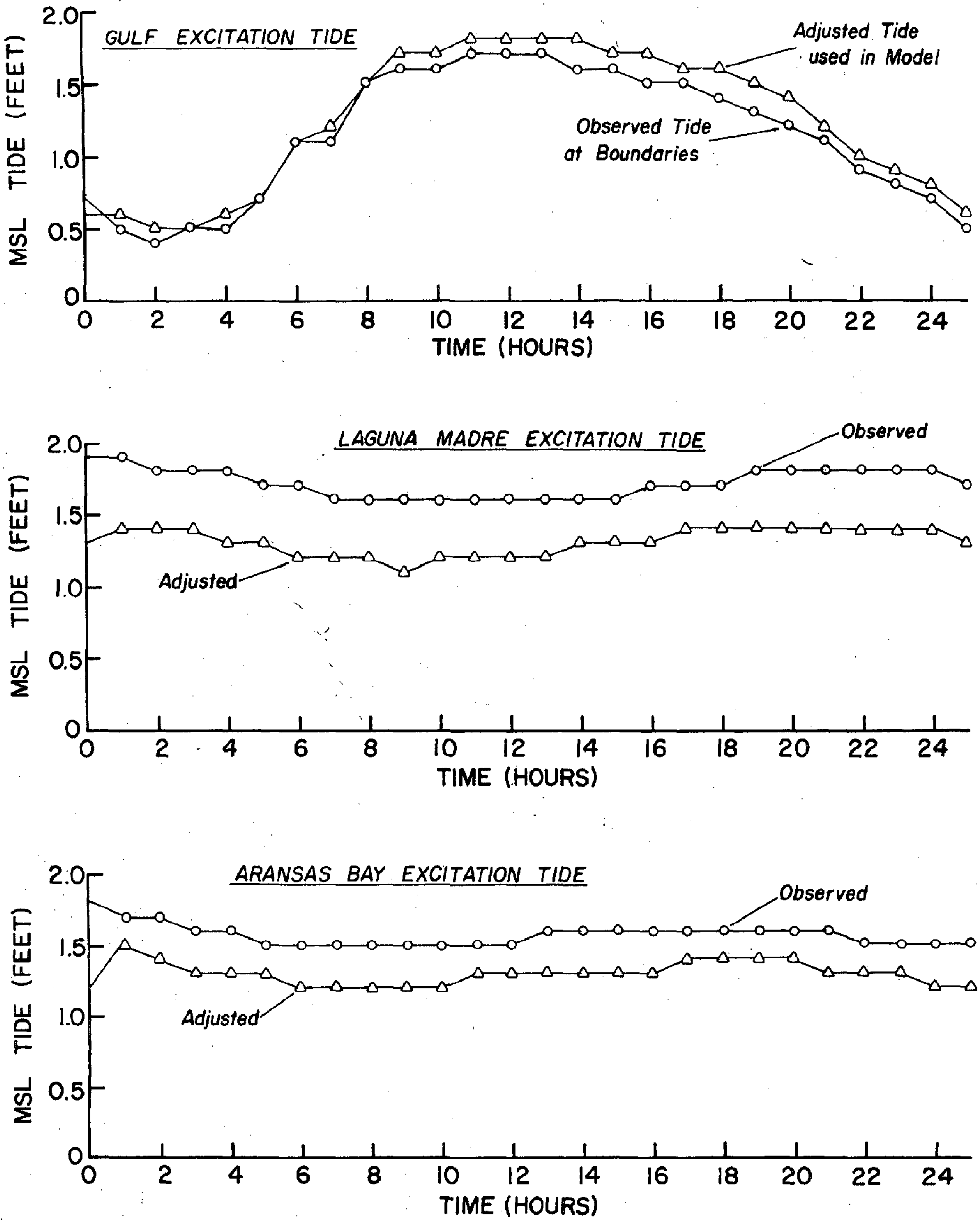


FIGURE IV-4D
OBSERVED AND ADJUSTED TIDES AT THE MODEL'S
BOUNDARIES FOR DATA PACKAGE XIX

(3) evaporation;
(4) precipitation; and
(5) hydrodynamic model output (velocities and depths).

Measured salinity concentrations at various locations in Corpus Christi Bay at different seasons over a few years period are used to "calibrate" and "verify" the conservative transport model. Dispersion coefficients successful for the Corpus Christi Bay were similar to those reported for other Texas estuaries. Furthermore, a sensitivity analysis was undertaken testing the transport model to variations in dispersion and evaporation coefficients (1). [See Appendix A for a presentation of these results.] Hence, the salinity transport model also is considered verified (1).

The hydrodynamic model, HYDTID, was run successfully for each Data Package (described in the next section). The output, net flows and depths, was then used with the conservative transport model, LOTRAN. The correlation between the computed TDS concentrations and the observed values was good. This indicates that the hydrodynamic output as well as the selected dispersion coefficients and the computed evaporation rate were acceptable. The dispersion coefficient was held constant at 3500 ft^2/sec for all of the reactive water quality models subsequently discussed.

Description of Data Packages

In addition to the data previously described for the hydrodynamic and conservative transport model, data for the operation of the non-conservative water quality transport models also require measurement of the concentrations at the Gulf, Upper Laguna Madre, and Aransas Bay boundaries, the Nueces River, the diversions and discharges. For "calibration" and "verification", estuarine water quality concentrations also are required.

The basic data from TWDB and USGS are assembled into Data Packages. Each Data Package covers a specific time period. The dates data were collected by TWDB and USGS serve as the starting and ending dates for each Data Package.

Eleven Data Packages were assembled for previous model development for the TWDB Corpus Christi-Aransas-Copano Bays system (10). A review of these data packages revealed that all were deficient except for total dissolved solids in the amount of water quality data necessary for verifying the water quality constituent transport models for the Corpus Christi Bay transport models. Hence, the data base was brought up to date by assembling eight "new" Data Packages encompassing the results of field studies by TWDB and USGS from July 19, 1971, to November 16, 1972.

Table IV-2 summarizes the basic data needs for model development, the Federal or State agency from which the data were received, the desired consistency of the data and how the data are utilized. Table IV-3 is a summary of the sufficiency of the data with respect to the new Data Packages. Data Packages XVIII for July 25, 1972, to September 20, 1972, was selected as the best Data Package to begin development and calibration of the Corpus Christi Bay System models. Data Packages XIV, XV, and XIX have also been used to further check the reliability of the models and the values used for the various reaction rates.

The average discharge flows from sewage treatment plants and industrial facilities were provided by the Water Needs and Residuals Management Task Force (see Table IV-4 and refer to Figure IV-3). Two fresh water streams enter the Corpus Christi Bay system. The Oso Creek flow was negligible in each case. The Nueces River discharges for the four Data Packages utilized are summarized in Table IV-5.

The meteorological parameters for these four Data Packages are presented in Table IV-6. The average wind magnitude and resultant wind direction are computed over the dates of the Data Package from data supplied by the State Clamatologist. Evaporation is computed by a method developed specifically for the Texas Coast by Brandes and Masch (14). Precipitation is averaged over each Data Package Period using the rainfall data from the weather station at the Corpus Christi International Airport.

The water quality of the Nueces River, diversions and waste discharges are presented in Table IV-7 based on data provided by the Water Needs and Residuals Management Task Force. Data from the TWDB - USGS for the Nueces River and the other estuarine boundary are reported in Tables IV-5 and IV-8, respectively.

Discussion of the Development of Water Quality Transport Models

The overall goal of this Task Force is the development and calibration of transport models which simulate the effect of changing river inflows and wastewater discharges on the concentrations of various water quality constituents in Corpus Christi Bay. The long-term transport model, LOTRAN, applied to Corpus Christi Bay has been shown in Chapter III to adequately simulate the transport of non-reactive or conservative substances such as total dissolved solids. Other water quality constituents which behave in a reactive or non-conservative manner (participating in chemical or biological reactions) have been adequately simulated in estuarine environments by assumming they behave as single constituent first-order reactants.

TABLE IV-2
DATA PACKAGE COMPOSITION AND USAGE

TIME SPAN	COOPERATING AGENCY	CONGRUOUS FEATURES	UTILIZATION
1-7 days: Water Quality Data	Texas Water Development Board/ U. S. Geological Survey	1. All constituents measured for substantial number of stations 2. Vertical homogenity	1. Initial concentrations for long term transport/reactive models 2. Needed because models are 2-dimensional areawise
30-90 days: Tides	U. S. Geological Survey	3. Phase and amplitudes uniform	3. Simplifies hydrodynamics
Fresh Water Inputs	U. S. Geological Survey	4. Magnitude constant and low 5. All constituents measured	4. Simplifies hydrodynamics 5. Inputs for transport/reactive models
Diversions	Texas Water Rights Commission	6. Accounted for and quantities known	6. Inputs for hydrodynamics model
Discharges	Environmental Protection Agency Texas Water Quality Board	7. Accounted for and quantities and quality measured	7. Inputs for hydrodynamic and transport/reactive models
Meteorology	U. S. Weather Service	8. Wind steady 9. Evaporation rate steady	8. Simplifies hydrodynamics 9. Simplifies hydrodynamics & input for transport/reactive models
		10. Low precipitation	10. Simplifies hydrodynamics & input for transport/reactive models
Water Quality Data	Texas Water Development Board/ U. S. Geological Survey	11. All constituents measured for substantial number of stations 12. Vertical homogenity	11. Final concentration for long term transport/reactive models 12. Needed because models are 2-dimensional areawise

TABLE IV-3

SUFFICIENCY OF DATA WITH RESPECT TO NEW DATA PACKAGES

Dates	6/9/71 to 7/20/71	7/20/71 to 9/14/71	11/11/71 to 1/27/72	1/27/72 to 3/28/72	3/28/72 to 6/1/72	6/1/72 to 7/25/72	7/25/72 to 9/20/72	9/20/72 to 11/16/72
	DATA PACKAGES							
DATA	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX
Initial Water Quality Data	-	+	+	+	+	+	+	+
Vertically Homogenity	-	-	+	+	+	+	+	+
Tides	-	-	+	+	+	+	+	+
River Inputs	+	+	+	+	-	-	+	-
River Constituents Data	+	+	+	+	+	+	+	+
Diversion Data	0	0	0	0	0	0	0	0
Discharge Data	0	0	0	0	0	0	0	0
Wind Data	+	+	+	+	+	+	+	+
Evaporation Data	+	+	+	+	+	+	+	+
Precipitation	+	+	+	-	-	-	+	+
Final Water Quality Data	+	+	+	+	+	+	+	+

+ Data or Conditions Sufficient

- Data or Conditions Not Sufficient

0 Estimates Provided by Water Needs & Residuals Management Task Force

TABLE IV-4
SUMMARY OF FLOWS FOR DATA PACKAGE
XIV, XV, XVIII, AND XIX

Inflow No.	Cell	Description	Flow (cfs)
1	I 2J8	Sewage Treatment Plants (STP)	0.4
2	I 9J8	Oil Production Facilities (OPF)	0.4
3	I15J8	STP	2.6
4	I 3J11	OPF	0.3
5	I 3J13	OPF	0.2
6	I 5J13	STP	0.2
7	I20J13	STP	1.1
8	I28J13	STP	0.8
9	I13J14	Oil Tanker Loading Facility	0.4
10	I 4J15	STP	13.2
11	I 2J16	STP and Oso Creek	5.3
12	I14J16	STP	0.3
13	I 4J17	OPF	0.1
14	I13J20	STP	0.3
15	I 6J22	STP	15.4
16	I 8J22	Diversion (Cooling Water)	936.0
17	I12J22	STP	0.7
18	I 7J23	Oil Refineries	126.2
19	I 8J23	Discharge (Cooling Water)	938.5
20	I10J24	OPF	0.1
21	I 6J25	OPF	0.2
22	I 7J26	Nueces River	*
23	I 9J26	OPF	6.6
24	I 8J27	OPF	0.1

* Flows vary with Data Package--See Table IV-5.

TABLE IV-5
AVERAGE NUECES RIVER DISCHARGES AND WATER QUALITY
USED IN FOUR DATA PACKAGES

Data Package	Flow (cfs)	BOD_5 (mg/l)	Total P (mg/l)	Org-N (mg/l)	NH_3-N (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)
XIV	371.5	0.5	0.2	0.8	0.01	0.00	0.00
XV	180.7	13.4	0.2	0.8	0.01	0.00	0.00
XVIII	85.4	4.2	0.07	0.80	0.04	0.00	0.00
XIX	399.0	3.0	0.13	0.80	0.04	0.00	0.05

TABLE IV-6
SUMMARY OF METEOROLOGICAL PARAMETERS FOR
DATA PACKAGES XIV, XV, XVIII, AND XIX

Data Package	Wind Velocity (knots)	Wind Angle Degrees From North	Evaporation Rate (inches/day)	Precipitation (inches/day)
XIV	10.0	80.0	0.12	0.00
XV	11.2	10.9	0.10	0.08
XVIII	8.6	120.0	0.30	0.00
XIX	9.9	110.0	0.20	0.15

TABLE IV-7
SUMMARY OF SOURCE CONCENTRATIONS

Inflow No.	Cell	Flow (cfs)	TDS (ppt)	Total-P (ppm)	Org-N (ppm)	Amm-N (ppm)	NO_2-N (ppm)	NO_3-N (ppm)	BOD_5 (ppm)
1	I 2J8	.4	2.9	8.00	14.60	15.10	0.00	0.00	19.1
2	I 9J8	.4	86.7	.02	10.20	26.10	0.00	1.00	560.0
3	I15J8	2.6	35.2	4.00	7.60	7.70	0.00	0.00	30.4
4	I 3J12	.3	93.4	.02	2.00	15.00	.01	.10	230.0
5	I 3J13	.2	79.3	.01	2.00	15.00	.01	.10	230.0
6	I 5J13	.2	.8	2.00	15.00	15.00	.01	.10	38.4
7	I20J14	1.1	.9	8.00	15.00	15.00	0.00	0.00	70.0
8	I28J14	.8	.9	8.00	15.00	15.00	0.00	0.00	7.0
9	I14J14	.4	9.7	.11	.24	2.20	0.00	.70	46.9
10	I 4J16	13.2	.9	8.00	15.00	15.00	0.00	0.00	4.0
11	I 2J17	5.3	16.5	4.20	7.80	10.70	.01	.32	132.0
12	I15J16	.3	.9	8.00	15.00	15.00	0.00	0.00	20.0
13	I 4J17	.1	156.0	.47	4.20	39.90	.30	.67	328.0
14	I14J20	.3	.9	8.00	15.00	15.00	0.00	0.00	100.0
15	I 6J22	15.4	.9	8.00	15.00	15.00	0.00	0.00	15.0
17	I13J22	.7	.9	8.00	15.00	15.00	0.00	0.00	4.0
18	I 7J24	127.3	29.0	.51	.24	.26	0.00	.01	26.4
19	I 8J23	938.5	33.9	.28	.28	.46	0.00	.22	30.0
20	I11J24	.1	85.9	.72	.13	.08	0.00	.01	2.4
21	I 6J25	.2	89.0	.05	.32	11.80	.14	.15	53.4
23	I10J26	6.6	26.1	4.80	7.10	9.80	.01	.10	29.1
24	I 8J28	.1	84.5	.05	1.70	16.10	.01	.21	147.0

TABLE IV-8
BOUNDARY WATER QUALITY CHARACTERISTICS
FOR FOUR DATA PACKAGES

Data Package	Boundary	BOD_5 (mg/l)	Total P (mg/l)	Org-N (mg/l)	NH_3-N (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)
XIV	Gulf	1.5	0.03	0.60	0.06	0.00	0.00
	Upper Laguna Madre	2.0	0.04	0.80	0.06	0.00	0.01
	Aransas Bay	2.0	0.04	0.80	0.06	0.00	0.01
XV	Gulf	1.5	0.04	0.6	0.12	0.00	0.00
	Upper Laguna Madre	2.0	0.04	0.8	0.10	0.00	0.01
	Aransas Bay	2.0	0.04	0.8	0.10	0.00	0.01
XVIII	Gulf	1.5	0.01	0.60	0.12	0.00	0.00
	Upper Laguna Madre	2.0	0.02	0.80	0.10	0.00	0.01
	Aransas Bay	2.0	0.02	0.80	0.10	0.00	0.01
XIX	Gulf	1.5	0.01	0.60	0.12	0.00	0.20
	Upper Laguna Madre	2.0	0.01	0.80	0.10	0.00	0.20
	Aransas Bay	2.0	0.02	0.80	0.10	0.00	0.20

This section is a discussion of the basic approach which was utilized to determine if the changes in total phosphorus, carbonaceous biochemical oxygen demand, dissolved oxygen and the nitrogen cycle constituents can be adequately represented by single or multi-constituent first-order reaction transport models.

Approach

As described in Chapter III, the fundamental equation for mass-transport is

$$\frac{\partial(C\bar{d})}{\partial t} + \frac{\partial(\bar{q}_x C)}{\partial x} + \frac{\partial(\bar{q}_y C)}{\partial y} = \frac{\partial}{\partial x}\left[E_x \frac{\partial(C\bar{d})}{\partial x}\right] + \frac{\partial}{\partial y}\left[E_y \frac{\partial(C\bar{d})}{\partial y}\right] \pm S_i \qquad \text{(III-6)}$$

The term, $\pm S_i$, represents the sources and sinks of the constituent for which the above equation is written. For the case in which first-order reactions are assumed to occur,

$$\pm S_i = Kc\bar{d},$$

where

K is the reaction rate coefficient (1/time)
C is the concentration (mg/l).

The approach taken herein involves experimentation with several of the coefficients reported in the literature in terms of the environmental conditions in Corpus Christi Bay and the available water quality data. Even if the changes in the water quality constituent are adequately represented by models using first-order reactions, the reaction rate coefficient, K, generally is highly sensitive to the system response. In some cases such as carbonaceous BOD, considerable information is available in the literature on the approximate value of these coefficients. With regard to total phosphorus and nitrogen, little information is available. Furthermore, in Texas as well as other estuarine systems, little is known concerning the effects of other variables such as temperature and salinity upon these coefficients.

Phosphorus

Phosphorus participates in a number of chemical reactions, including acid-base, precipitation and complexation. A number of the cations chemically participating with phosphorus in the above reactions also change with the oxidation-reduction potential. Since most of the estuary is shallow, the oxidation-reduction potential was not expected to become negative. Also measurements on the various cations, i.e., iron, were not available. Furthermore, each of the above reactions are affected by the ionic strength of the water which radically changes from the mouth of the Nueces River to the Gulf.

Phosphorus also is utilized by bacteria, phytoplankton and rooted vegetation as a nutrient. Plant activity also is a function of temperature and light penetration in addition to a number of other variables such as salinity. Information was available from the Task Force on Biological Uses Criteria on the location of the biotopes where the phytoplankton and rooted vegetation dominate and on estimated productivity values from the literature. But no information was available on organism density nor biomass. However, in their evaluation of the Corpus Christi Bay System the Task Force on Biological Uses Criteria evaluated that phosphorus generally was in excess in this estuarine system and nitrogen was the more likely critical nutrient.

In light of the host of various reactions which could occur, the initial approach was to utilize an over-all first-order term to simulate all of the above reactions. Hence, the Corpus Christi Bay slowly-varying mass transport model, LOTRAN, was modified to include a first-order reaction term which behaved as a sink in the single constituent total phosphorus transport model. The sink term thus became

$$S_i = K_p P\overline{d}$$

where

K_p = overall first-order sink reaction coefficient

P = concentration of total phosphorus

Subsequently, experimentation was undertaken with the range of magnitude of the overall phosphorus reaction coefficients cited in the literature to determine if an adequate simulation of the observed total phosphorus in Data Package XVIII could be obtained. The POTRAN model was considered to "fit" when the computed values fell within the ranges of the observed data for the maximum number of stations. Figure IV-5 locates the sampling stations used at some time in the Corpus Christi Bay system. Usually one to three of the observed stations on each line were sampled. Subsequently, the "fitted" K_p coefficient was tried on the other Data Packages, which were obtained in different seasons of the year.

The best "fitted" coefficients for the four Data Packages are presented in Table IV-9. Comparison between observed and computed total phosphorus concentrations are presented in Table IV-10. It is obvious that there is a wide variation between the computed and observed values for one or two sampling stations in each Data Package. However, for all the stations, the

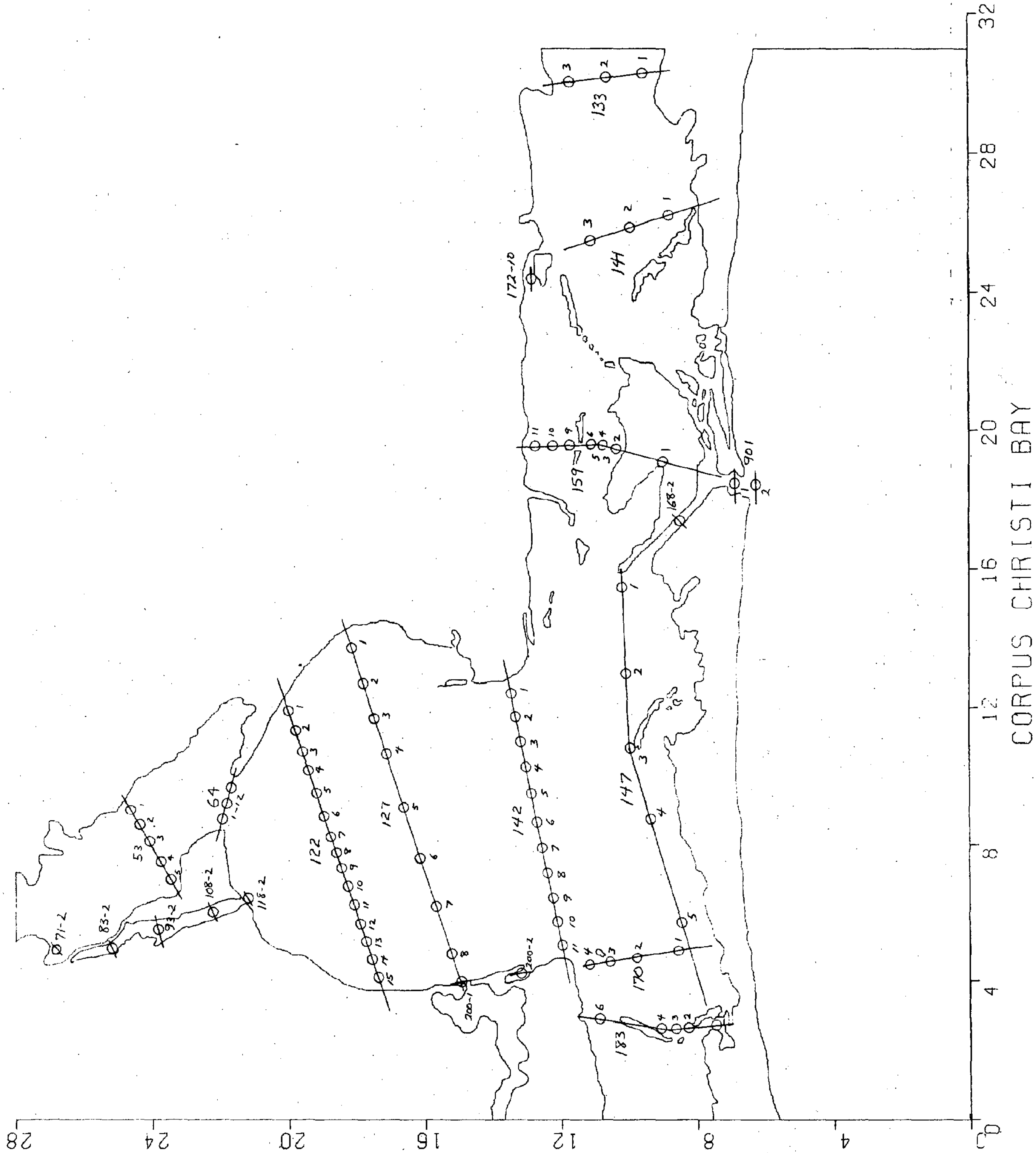


FIGURE IV-5
USGS/TWDB WATER QUALITY SAMPLING STATIONS AT VARIOUS TIMES
IN THE CORPUS CHRISTI BAY SYSTEM

TABLE IV-9

"FITTED" REACTION COEFFICIENTS

Water Quality Constituent	Coefficient	Data Packages XIV	XV	XVIII	XIX
Total Phosphorus	K_p	0.014	0.01	0.03	0.02
BOD_5	K_b	0.05	0.037	0.037	0.037
Nitrogen	K_{n1}	0.01	0.01	0.01	0.01
	K_{n2}	0.02	0.02	0.02	0.02
	K_{n3}	0.60	0.60	0.60	0.60
	K_{n4}	0.10	0.10	0.10	0.10
	K_{n5}	0.30	0.30	0.30	0.30

TABLE IV-10

COMPARISON OF OBSERVED AND COMPUTED TOTAL PHOSPHORUS CONCENTRATIONS (mg/l)

Data Package	Observation Line-Site*	Number of Observations	Observed			Computed
			Average	High	Low	
XVIII	53-2	1	.07			.06
	53-4	1	.07			.06
	108-2	2	.135	.19	.08	.08
	122-2	2	.03	.03	.03	.04
	122-6	2	.04	.04	.04	.04
	122-12	2	.03	.04	.02	.04
	142-2	2	.03	.04	.02	.03
	142-10	2	.025	.03	.02	.03
	147-2	2	.025	.03	.02	.02
	147-5	2	.025	.03	.02	.03
	901-2	2	.01	.01	.01	.01
	141-1	2	.02	.02	.02	.02
	141-3	2	.02	.02	.02	.02
	159-8	2	.015	.02	.01	.02
XIV	53-2	2	.21	.21	.21	.08
	53-4	1	.36			.07
	53-5	1	.41			.07
	64-9	1	.11			.05
	122-6	3	.056	.07	.05	.05
	127-2	2	.035	.04	.03	.04
	142-1	3	.043	.05	.03	.04
	147-1	2	.03	.03	.03	.04
	147-5	2	.045	.05	.04	.04
	168-2	2	.03	.03	.03	.03
	170-3	2	.04	.04	.04	.04
	141-1	2	.035	.040	.030	.04
	141-3	2	.04	.04	.04	.04
	172-10	2	.03	.03	.03	.04
XV	53-2	1	.18			.11
	64-9	2	.105	.11	.10	.08
	71-2	2	.165	.21	.12	.12
	122-6	3	.043	.06	.03	.08
	127-2	2	.055	.07	.04	.07
	127-6	2	.045	.05	.04	
	142-1	3	.033	.04	.03	.07
	142-6	2	.135	.21	.06	.07
	147-2	2	.05	.05	.05	.07
	147-5	2	.05	.06	.04	.06
	168-2	2	.035	.04	.03	.06
	183-3	2	.05	.06	.04	.05
	200-2	1	.09			.08
XIX	53-2	1	.05			.04
	53-4	1	.05			.04
	64-9	2	.03	.03	.03	.03
	71-2	2	.25	.26	.24	.05
	108-2	2	.055	.08	.03	.06
	122-6	3	.06	.08	.02	.03
	142-1	3	.01	.02	.01	.03
	142-6	2	.04	.07	.01	.03
	147-2	2	.005	.01	.00	.02
	168-2	2	.01	.02	.00	.01
	200-2	1	.27			.04
	901-1	2	.025	.03	.02	.01
	141-1	2	.09	.10	.08	.02
	172-10	2	.02	.02	.02	.02

* See Figure IV-5

agreement between computed and observed total phosphorus values is acceptable considering what is included in such estuarine total phosphorus analyses (particulate, live organisms, detritus) and the large coefficient of variance at these relatively low concentrations.

The K_p coefficient is the same order of magnitude for all four Data Packages. A correlation was attempted between K_p and different variables such as temperature and salinity. As to be expected for such a gross overall reaction coefficient, no correlation was found.

BOD and DO

The biochemical oxygen demand and dissolved oxygen water quality transport model, DOTRAN, should incorporate the following linkages:

(1) oxidation of carbonaceous matter;
(2) oxidation of ammonia;
(3) benthic oxygen demand;
(4) reaeration from the atmosphere; and
(5) production and respiration of oxygen by phytoplankton.

The oxidation of carbonaceous material was approximated using typical first-order reaction rates reported in the literature.

$$S_i = K_b B \overline{d}$$

where

K_b = overall reaction rate coefficient

B = carbonaceous BOD concentration.

The only data available were BOD_5 concentrations. These values were generally below the statistical value for analytical accuracy. It was assumed that the carbonaceous BOD was represented by the BOD_5. Once again Data Package XVIII was utilized in the first attempt to "fit" the coefficient. The coefficients for the four Data Packages are reported in Table IV-9. The comparison between observed and computed BOD_5 concentrations are reported in Table IV-11.

Except for Data Package XIX, the correlation between observed and computed BOD_5 concentrations were good. The gross overall BOD_5 reaction rate coefficient was the same for all Data Packages except XIV. The reason for this small change could not be found.

TABLE IV-11
COMPARISON OF OBSERVED AND COMPUTED
BOD_5 CONCENTRATIONS (mg/l)

Data Package	Observation Line-Site*	Number of Observations	Observed Average	Observed High	Observed Low	Computed
XVIII	53-2	1	3.9			4.9
	53-4	1	4.6			5.0
	108-2	2	4.05	5.8	2.3	4.9
	122-2	2	2.55	2.7	2.4	2.6
	122-6	2	3.3	3.3	3.3	2.7
	122-12	2	2.4	3.1	1.7	2.4
	142-2	2	2.2	2.8	1.6	2.0
	142-10	2	1.9	2.2	1.6	2.0
	147-2	2	3.05	3.3	2.8	1.8
	147-5	2	2.55	2.8	2.3	1.9
	901-2	2	1.75	2.5	1.0	1.5
XIV	122-6	2	1.75	1.8	1.7	2.6
	127-2	2	1.8	1.8	1.8	2.1
	142-1	2	2.0	2.1	1.9	1.8
	147-1	2	1.8	1.9	1.7	1.5
	168-2	2	1.75	2.2	1.3	1.4
	170-3	2	1.6	1.8	1.4	1.7
	141-1	2	1.6	1.6	1.6	1.7
	141-3	2	1.45	1.7	1.2	1.7
	172-10	2	1.8	1.9	1.7	1.6
XV	53-2	1	0.8			2.7
	64-9	2	1.15	1.2	1.1	2.1
	71-2	2	5.45	8.8	2.1	3.5
	122-6	2	1.0	1.1	.9	2.1
	127-2	2	1.3	1.4	1.2	2.0
	142-1	2	1.05	1.3	.8	1.9
	142-6	2	2.35	2.5	2.2	2.0
	147-2	2	1.35	1.5	1.2	1.9
	147-5	2	2.55	3.1	2.0	1.7
	168-2	2	0.9	1.0	.8	1.6
	183-3	2	4.4	4.6	4.2	1.3
XIX	53-2	1	2.6			4.6
	53-4	1	2.7			4.8
	64-9	2	1.6	2.2	1.0	2.9
	71-2	2	3.5	3.5	3.5	4.0
	108-2	2	2.95	3.2	2.7	4.0
	122-6	2	3.25	3.3	3.2	2.6
	142-1	2	2.2	2.8	1.6	2.0
	142-6	2	1.85	2.0	1.7	2.0
	147-2	2	3.05	3.3	2.8	1.8
	147-5	2	2.2	2.7	1.7	1.9
	168-2	2	1.15	1.5	.8	1.5
	183-3	2	1.4	1.8	1.0	1.9
	901-1	2	1.75	2.1	1.4	1.5

* See Figure IV-5

The other components of the DOTRAN model were then evaluated. The oxidation of ammonia to nitrite and then to nitrate will be discussed in the next section on nitrogen. Some benthic oxygen uptake studies have been undertaken in Tule Channel but these results in this small polluted area are not representative of the rest of the bay. Atmospheric reaeration is dependent upon the turbulence which is approximated through knowledge of the depths and velocities for the estuary which is provided by the HYDTID model. The saturation value for the oxygen concentration is dependent upon the salt concentration which can be obtained through the total dissolved solids prediction by the LOTRAN model. Little, if any, information, however, is available on plant photosynthesis and respiration. Hence, considerable professional experience was utilized to develop the model.

The observed field data for the Corpus Christi Bay system were collected during the daylight hours. Some values near the sediments in Tule Channel had dissolved oxygen concentrations less than saturation. However, the one mile grid scheme used for Corpus Christi Bay was not adequate for modeling the Inner Harbor. Unfortunately, all the other observed DO values were higher than saturation. Also nearly all of the predicted DO values were near saturation. An example of the situation is presented in Figure IV-6. Thus, although there was reasonable simulation of the conservative and other non-conservative water quality constituents, there was not any agreement between predicted and observed dissolved oxygen values. Hence, the many coefficients which needed "tuning" could not be evaluated.

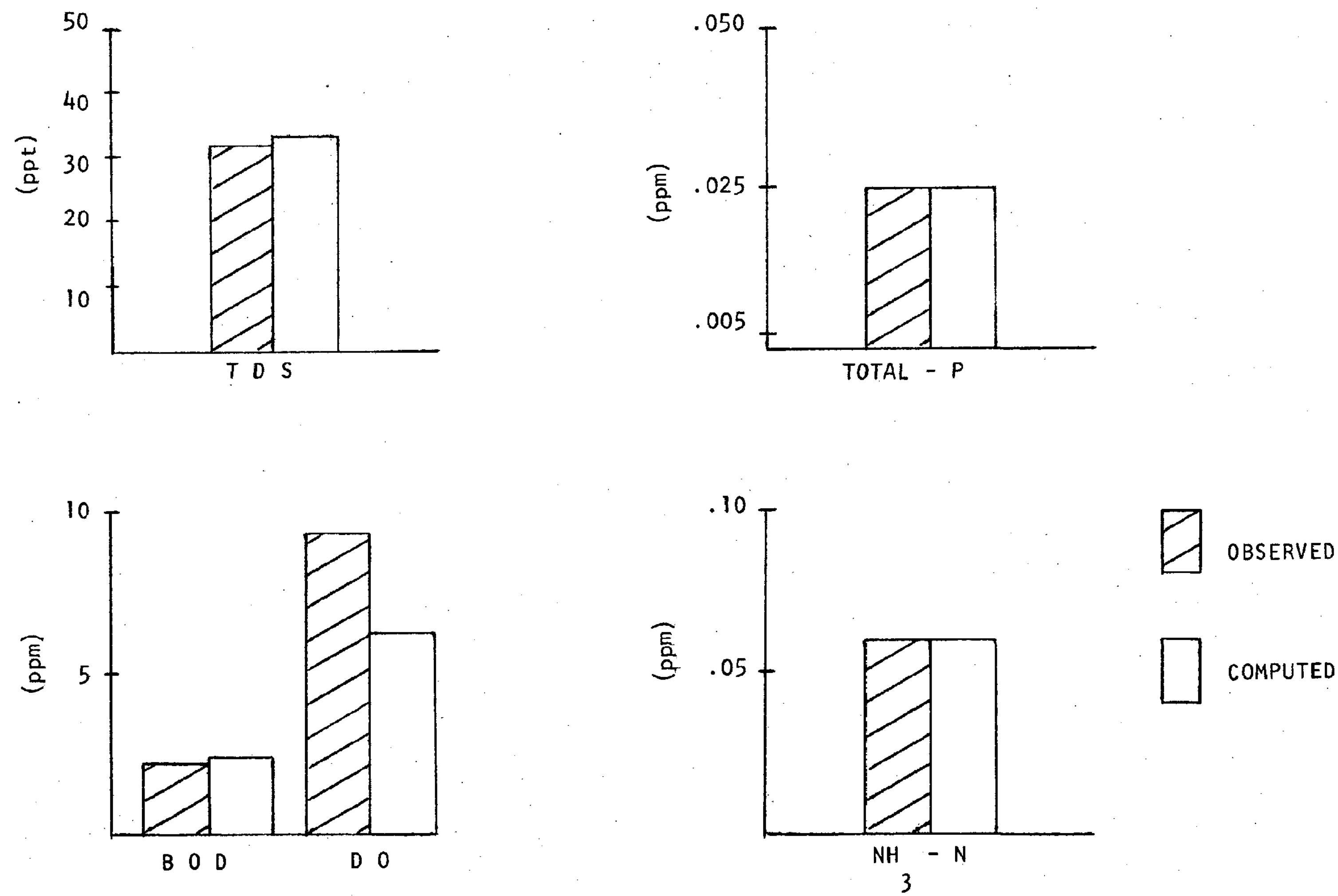
The purpose for the dissolved oxygen model in the project was to estimate if the dissolved oxygen in the estuary deteriorated significantly for various hypothetical coastal zone management policies for the Coastal Bend COG. Because of the problems previously discussed, a simpler model considering only degradation of carbonaceous organic matter and reaeration was utilized for this purpose. Thus, higher wastewater loadings expected in the future with some of the policies were run with this uncalibrated model. No significant depletion of dissolved oxygen below saturation values was found. Hence, dissolved oxygen was not considered a sensitive response variable for this estuarine system for the policies considered. Therefore, because of time limitations, further work on dissolved oxygen modeling was left until the third year of the project.

Nitrogen

In investigating the incorporation of nitrogen in the water quality transport models, eight possible reactions were considered:

(1) chemical and biological decomposition of organic nitrogen to ammonia;

FIGURE IV-6
COMPARISONS OF MEASURED AND COMPUTED CONSTITUENT CONCENTRATIONS
FOR DATA PACKAGE XVIII - STATION 147-2



(2) bacterial nitrification of ammonia to nitrite;
(3) further nitrification of nitrite to nitrate;
(4) phytoplankton utilization of ammonia;
(5) phytoplankton utilization of nitrate;
(6) respiration rate of phytoplankton;
(7) deposition of the phytoplankton cells; and
(8) death and/or predation of phytoplankton releasing organic nitrogen.

Because of the physiographic and hydrodynamic characteristics of Corpus Christi Bay, anaerobic processes were considered negligible. Although field studies have provided sufficient data on ammonia, nitrite and nitrate, little data are available on organic nitrogen. Likewise, little or no data were available on nitrogen uptake rates or nitrogen content of the biomass of plankton and rooted vegetation. Thus, the nitrogen transport model was developed in stages first considering the nitrification process, then the phytoplankton uptake and subsequently the feedback loops. Reaction rate coefficients from the literature were utilized first and subsequently changed so as to have the model predictions correspond to the observed field results in a particular Data Package. Subsequently, other Data Packages will be utilized.

However, it became quickly apparent that without organic nitrogen and plant nitrogen biomass measurements, none of the coefficients in this complicated model could be "tuned". Also, reasonable results were obtained without consideration of the deposition of plant material and the feedback of organic nitrogen to the estuarine system.

Hence, the simplest of first-order reaction rates first considered included:

$S_1 = K_{n1} N_1 \overline{d}$ (for organic nitrogen)

$S_2 = K_{n1} N_1 \overline{d} - K_{n2} N_2 \overline{d} - K_5 N_2 \overline{d}$ (for ammonia)

$S_3 = K_{n2} N_2 \overline{d} - K_{n3} N_3 \overline{d}$ (for nitrite)

$S_4 = K_{n3} N_3 \overline{d} - K_{n4} N_4 \overline{d}$ (for nitrate)

$S_5 = K_{n4} N_4 \overline{d} + K_{n5} N_2 \overline{d}$ (for plant nitrogen biomass)

where

S = source or sink term [organic N (1), ammonia N (2), nitrite N (3), nitrate N (4), and plant N (5)]

K_n = reaction rate coefficient

K_{n1} for degradation of organic nitrogen

K_{n2} for oxidation of ammonia to nitrite

K_{n3} for oxidation of nitrite to nitrate

K_{n4} for plant uptake of nitrate

K_{n5} for plant uptake of ammonia

The reaction rate coefficients used for the data are presented in Table IV-9. The comparison between observed and predicted ammonia N, nitrite N, and nitrate N measurements are presented in Table IV-12. Values not presented for the various samples obtained were zero. As to be expected with a simplified model which ignores major reactions, there are significant differences between observed and computed nitrogen concentrations at a few sampling stations for all the Data Packages. However, a reasonable agreement was found using the same value for the coefficients in all four Data Packages.

TABLE IV-12
COMPARISON OF OBSERVED AND COMPUTED
NITROGEN CONCENTRATIONS (mg/l)

Data Package	Nitrogen Species	Observation Line-Site*	Number of Observations	Observed Average	Observed High	Observed Low	Computed
XVIII	NH_3-N	108-2	2	.24	.38	.100	.14
		142-2	2	.095	.10	.09	.07
		142-10	2	.045	.06	.03	.08
		147-2	2	.06	.07	.05	.08
		147-5	2	.135	.16	.11	.08
		901-2	2	.050	.10	.04	.11
		141-1	2	.140	.17	.11	.09
		141-3	2	.040	.050	.030	.09
	NO_2-N	108-2	2	.00015	.003	.000	.00
		142-10	2	.0001	.002	.000	.00
	NO_3-N	53-4	1	.020			.02
		108-2	2	.015	.030	.000	.00
XIV	NH_3-N	53-2	2	.145	.190	.100	.17
		53-4	1	.800			.17
		53-5	1	.550			.17
		64-9	2	.115	.180	.050	.16
		122-6	3	.060	.090	.040	.16
		127-2	2	.050	.050	.050	.16
		142-1	3	.080	.100	.050	.15
		147-1	2	.430	.440	.420	.13
		170-3	2	.200	.400	.000	.14
		141-1	2	.045	.050	.040	.08
		141-3	2	.080	.090	.070	.08
		172-10	2	.065	.080	.050	.08
	NO_2-N	53-2	2	.005	.010	.000	.01
		53-5	2	.014	.028	.000	.01
		122-6	3	.007	.022	.000	.01
		142-1	3	.010	.010	.000	.01
		147-1	2	.005	.010	.000	.00
		168-2	2	.028	.034	.022	.00
XV	NH_3-N	53-2	1	.14			.11
		64-9	2	.140	.160	.120	.08
		71-2	2	.08	.160	.000	.08
		122-6	3	.020	.030	.000	.08
		127-2	2	.005	.010	.000	.07
		127-6	2	.015	.030	.000	
		142-1	3	.043	.070	.000	.07
		142-6	2	.050	.080	.020	.07
		147-5	2	.005	.010	.000	.07
		183-3	2	.015	.020	.010	.09
	NO_2-N	53-2	1	.008			.00
		64-9	2	.014	.014	.014	.00
		71-2	2	.006	.006	.006	.00
		122-6	3	.020	.030	.000	.00
		127-2	2	.004	.004	.004	.00
		127-6	2	.004	.004	.004	
		142-1	3	.0036	.005	.003	.00
		142-6	2	.005	.005	.005	.00
		147-2	2	.003	.003	.003	.00
		147-5	2	.0035	.004	.003	.00
		168-2	2	.002	.002	.002	.00
		183-3	2	.0065	.007	.006	.00
		200-2	1	.005			.00
	NO_3-N	142-6	2	.010	.020	.000	.01
		168-2	2	.010	.020	.000	.00
XIX	NH_3-N	64-9	2	.005	.010	.000	.09
		71-2	2	.180	.210	.150	.09
		108-2	2	.035	.050	.020	.14
		122-6	3	.003	.010	.000	.09
		142-1	3	.060	.130	.050	.08
		142-6	2	.035	.060	.010	.08
		147-2	2	.015	.030	.000	.08
		168-2	2	.020	.030	.010	.10
		183-3	2	.060	.100	.020	.10
		200-2	1	.260			.09
		901-1	2	.020	.030	.010	.11
		141-1	2	.055	.060	.050	.09
		172-10	2	.035	.060	.010	.09

TABLE IV-12
COMPARISON OF OBSERVED AND COMPUTED
NITROGEN CONCENTRATIONS (mg/l)
(CONTINUED)

Data Package	Nitrogen Species	Observation Line-Site*	Number of Observations	Average	Observed High	Low	Computed
	NO_2-N	71-2	2	.003	.003	.003	.00
		108-2	2	.0025	.005	.000	.00
		168-2	2	.0275	.034	.021	.00
		200-2	1	.090			.00
		901-1	2	.043	.045	.041	.00
	NO_3-N	22-2	1	.010			
		71-2	2	.010	.020	.000	.01
		108-2	2	.010	.020	.000	.02
		142-6	2	.005	.010	.000	.01
		168-2	2	.060	.090	.030	.00
		183-3	2	.005	.010	.000	.00
		200-2	1	.200			.01
		901-1	2	.100	.100	.100	.00
		172-10	2	.005	.010	.000	.00

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1) Existing TWDB hydrodynamics and conservative transport models for a multiple bay complex were adapted to Corpus Christi Bay to meet the overall needs of the project. A large number of Data Packages were utilized to substantiate the reliability of these two models. Sensitivity analyses also were undertaken. The models are considered "verified".

2) The Corpus Christi Bay conservative transport model was modified to include a first order reaction term which behaved as a sink in the single constituent total phosphorus transport model. The order of magnitude and trend of the observed total phosphorus changes in Corpus Christi Bay were well simulated by the model. However, the model can only be considered "calibrated" because different rate coefficients (although of the same order of magnitude) had to be used for the four Data Packages and the coefficient could not be correlated to environmental conditions such as temperature and salinity.

3) A similar approach and results were found with the BOD_5 modeling.

4) Unfortunately, field data used to calibrate the dissolved oxygen model were collected in daylight hours and supersaturation always existed. Hence, the multi-component reaction dissolved oxygen model could not be "calibrated".

5) A multi-component first order reaction model was developed for the nitrogen cycle including degradation of organic nitrogen, nitrification and plant uptake, but not plant settling, decomposition, and nitrogen recycling. Agreement between observed and computed nitrogen values was acceptable, the same reaction coefficients being applicable to all four Data Packages.

Recommendations

1) The field work of local, state and federal agencies in Corpus Christi Bay (coordinated by TWDB) is a necessity for any type of coastal zone management in Texas. A field and modeling program (described partially below) has been planned and implemented by TWDB to obtain missing data for all the Texas estuaries. Funding for such work must be continued on a long-term basis.

The TWDB program is one of the very few in the nation in which flow exchange measurements are obtained at different locations in an estuary over a tidal cycle so that hydrodynamic models can be calibrated and verified and sensitivity analyses can be conducted. Another flow measurement field program is planned for the Corpus Christi Bay by TWDB for 1974. The results from this TWDB field program should once again be utilized in the next year of this research project.

As regards water quality modeling, the primary field data lacking for Corpus Christi Bay are diurnal dissolved oxygen measurements. With such data plant photosynthesis and respiration rates can be estimated so that a dissolved oxygen model can be calibrated. In addition phytoplankton, zooplankton, and rooted vegetation biomass and nutrient content are required for modeling for current coastal zone planning and management questions. All such field work has been implemented since 1972 in Corpus Christi Bay by TWDB.

Basic research is required on plant sedimentation, decomposition, and nutrient recycle. Based on their own research work, TWDB also has initiated such studies in another Texas estuary and these results should be applicable to Corpus Christi Bay.

2) The estuarine models developed thus far in this research project are typical of many others which have constructed around the nation - the models lack an analytical criterion for calibration as well as an analysis of numerical solution accuracy. This need is one of the primary objectives of the estuarine modeling task force in the third year of the research effort.

3) To demonstrate a methodology for evaluating the environmental impact of various hypothetical coastal management policies for the Coastal Bend region using the data and analytical techniques available to State agencies (1972), the water quality modeling effort as described in this report was sufficient. However, for the current coastal zone planning and management questions, estuarine ecosystem modeling is required. An extraordinary effort has been undertaken in estuarine ecosystem modeling for San Antonio Bay by TWDB since 1972. During the third year of this research project, it is hoped that a considerable portion of such a model can be adapted to Corpus Christi Bay.

4) The coastal zone planning and management questions arising also appear to require an optimization of wastewater return flows and quality. Such optimization problems can be highly dimensional for Texas estuaries if reasonable grid size is utilized. In general, decompositional methods of large scale optimization may have to be used to solve such problems. However, because the number of wastewater return flows compared to the number of cells in the grid scheme for Corpus Christi Bay System is relatively small, the development of a variational model which would reduce the dimensionality of the problem may be possible.

5) To effectively analyze the effect of freshwater inflows (including precipitation and evaporation plus industrial, municipal, and agricultural return flows) on the Corpus Christi Bay ecosystem, a stochastic approach is required. The statistical analysis should be at least on a monthly basis because of the large variation of rainfall and evaporation affecting industrial, municipal and agricultural water demands. Also consideration is required of the proposed Choke Canyon reservoir in addition to present Lake Corpus Christi as the water supply source on the Nueces River.

BIBLIOGRAPHY

(1) Murfee, George W., Frank D. Masch, Jr., and E. Gus Fruh. "Establishment of Operational Guidelines for Texas Coastal Zone Management: Interim Report on Estuarine Modeling", Interim Report to NSF-RANN and Office of the Governor of Texas, by The University of Texas at Austin, May, 1973.

(2) Currington, H. W., Wells, D. M., Masch, F. D., and Copeland, B. J., "Return Flows--Impact on Texas Bays", Technical Report to the Texas Water Development Board, January, 1966, 35 pp. (with Appendices).

(3) Lockwood, M. G. and Carothers, H. P., "Preservation of Estuaries by Tidal Inlets", Journal, Waterways and Harbors Division, Proceedings, ASCE, Vol. 93, No. WW4, November, 1967, pp. 231-256.

(4) Masch, F. D., et al, "A Numerical Model for the Simulation of Tidal Hydrodynamics in Shallow Irregular Estuaries", Tech. Rep. HYD 12-6901, Hydraulic Engineering Laboratory, The University of Texas at Austin, February, 1969, 123 pp.

(5) Masch, F. D. and Brandes, R. J., "Tidal Hydrodynamic Simulation in Shallow Estuaries", Tech. Rep. HYD 12-7102, Hydraulic Engineering Laboratory, The University of Texas at Austin, August, 1971, 171 pp.

(6) Brandes, R. J. and Masch, F. D., "A Slowly-Varying Conservative Transport Model for Estuaries", Tech. Rep. HYD 12-7103, Hydraulic Engineering Laboratory, The University of Texas at Austin, August, 1971, 171 pp.

(7) Masch, F. D., Warayanan, M., and Brandes, R. J., "A Short-Term Conservative Transport Model for Shallow Estuaries", Tech. Rep. HYD 12-7104, Hydraulic Engineering Laboratory, The University of Texas at Austin, August 1971, 90 pp.

(8) Shankar, V. J. and Masch, F. D., "Influence of Tidal Inlets on Salinity and Related Phenomena in Estuaries", Tech. Rep. HYD 16-7001, Hydraulic Engineering Laboratory, The University of Texas at Austin, November 1970, 107 pp.

(9) Masch, F. D., et al, "Tidal Hydrodynamic and Salinity Models for San Antonio and Matagorda Bays, Texas", Report to the Texas Water Development Board, June 1971, 130 pp.

(10) Masch, F. D., et al, "Tidal Hydrodynamics and Salinity Models for Corpus Christi and Aransas Bays, Texas", Report to the Texas Water Development Board, September 1972, 98 pp.

(11) Hahl, D. C. and Ratzlaff, K. W., "Chemical and Physical Characteristics of Water in Estuaries in Texas", October 1967 - September 1968, Texas Water Development Board Report 117, May 1970.

(12) Hahl, D. C. and Ratzlaff, K. W., "Chemical and Physical Characteristics of Water in Estuaries in Texas", October 1968 - September 1969, Texas Water Development Board Report 144, April 1972.

(13) Southwest Research Institute, "Water Quality Baseline Study for Corpus Christi Bay from June 1970 to June 1971", January 1972.

(14) Masch, F. D., et al, "Tidal Hydrodynamics and Salinity Models for Coastal Bays - Evaporation Considerations", Report to Texas Water Development Board, September 1972, 40 pp.

(15) Dronkers, J. J., Tidal Computations in Rivers and Coastal Waters, North Holland Publishing Co., Amsterdam, Publishers: John Wiley and Sons, Inc., New York and London, 1964.

(16) Roll, H. V., "Physics of the Marine Atmosphere", International Geophysics Series, Vol. 7, Academic Press, New York and London, 1965, pp. 158-159.

(17) Reid, R. O. and Bodine, B. R., "Numerical Model for Storm Surges in Galveston Bay", Journal, Waterways and Harbors Division, Proceedings, ASCE, Vol. 94, No. WW1, February 1968, pp 33-57.

(18) Harleman, D. R. F. (1966). "Diffusion Processes in Stratified Flow", Chap. 12 and "Pollution in Estuaries", Chap. 14, Estuary and Coastline Hydrodynamics, (Editor A. Ippen), McGraw-Hill Book Co., Inc., New York.

(19) Daily, J. W. and Harleman, D. R. F. (1966). Fluid Dynamics, Addison-Wesley Publishing Company, Inc., Reading Mass., pp. 424-437.

(20) Holley, E. R. (1969). "Unified View of Diffusion and Dispersion", J. Hyd. Div., Proceedings, ASCE, Vol. 95, No. Hy2, pp. 621-631.

(21) Clark, Leo J. and Jaworski, Norbert A., "Nutrient Transport and Dissolved Oxygen Budget Studies in the Potomac Estuary", U. S. Environmental Protection Agency Technical Report 37, October 1972.

(22) Peaceman, D. W. and Rachford, H. H., Jr. (1955). "The Numerical Solution of Parabolic and Elliptic Differential Equations", J. Soc. Indust. Appl. Math., 3, No. 1, pp. 28-41.

(23) Douglas, J. and Gunn, J. (1964). "A General Formulation of Alternating Direction Methods", Numerical Mathematics, Vol. 6.

(24) Carnahan, B., Luther, H. A., and Wilkes, J. O. (1969). Applied Numerical Methods, John Wiley and Sons, Inc., New York.

(25) Gebhard, T. C. and Masch, F. D. (1969). "Evaluation of Micro-Models for Near Surface Dispersion in Reservoirs", Tech. Rep. HYD 10-6902, Hydraulic Engineering Laboratory, The University of Texas at Austin, 141 pages.

(26) Bruce, G. F., Peaceman, D. W., Rachford, H. H. and Rice, J. D. (1953). "Calculation of Unsteady-State Gas Flow through Porous Media", Trans. Amer. Inst. Mining and Met. Engrs., Vol. 198, pp. 79-92.

APPENDIX

PERTINENT SECTIONS ON DEVELOPMENT AND SENSITIVITY ANALYSIS OF HYDRODYNAMIC AND SALINITY TRANSPORT MODELS FOR THE CORPUS CHRISTI BAY SYSTEM

from

"INTERIM REPORT ON ESTUARINE MODELING"

by

G. W. Murfee
F. D. Masch
E. G. Fruh

May, 1973

APPENDIX A
CORPUS CHRISTI BAY SYSTEM MODEL

The Corpus Christi-Aransas-Copano Bays System Model developed by Masch and Brandes for the TWDB (2) was modified at the outset of the study to produce a smaller model with capability to include more inputs and more resolution if necessary and to facilitate the development of additional water quality models specifically for the Corpus Christi Bay environs. A survey of the more recent available data collected by the TWDB/USGS sampling program was undertaken to supplement the data used in the previous TWDB modeling studies (2). The recent data, after being grouped into Data Packages, were evaluated and a final determination was made as to which Data Packages would be used as the basic data to calibrate the newly developed Corpus Christi Bay System Model.

Development of Corpus Christi Bay System Model

Modifications to the TWDB hydrodynamic and transport models consisted of a reduction in the size of the area modeled, adding diversions and discharges unaccounted for previously, and adjusting excitation tides at the new boundaries to correct for apparent datum discrepancies. The Corpus Christi Bay System Model intended for use in this project includes Corpus Christi, Nueces, Oso and Redfish Bays and the portion of Aransas Bay from Redfish Bay eastward to the Rockport tide gage. Figure A-1 illustrates the area covered by these models.

The main problem in reducing the coverage of the original TWDB models was to develop the boundary conditions at the Rockport boundary of the models so that the Corpus Christi Bay System Model would properly simulate the hydrodynamics and transport across this section. Rockport was selected as the eastern boundary of the model because tide gage records and water quality data are available at this location. This has the advantage of being able to excite the models with actual field data rather than with simulated conditions.

The reduction in model size will allow additional model resolution if deemed necessary in the future. Currently, the size of the individual computational cells, which in total form the grid scheme depicted in Figure A-2 is one nautical mile square. With the newly developed models, the resolution and/or computer storage can be increased by approximately thirty percent without increasing computer expenses now used in the TWDB models.

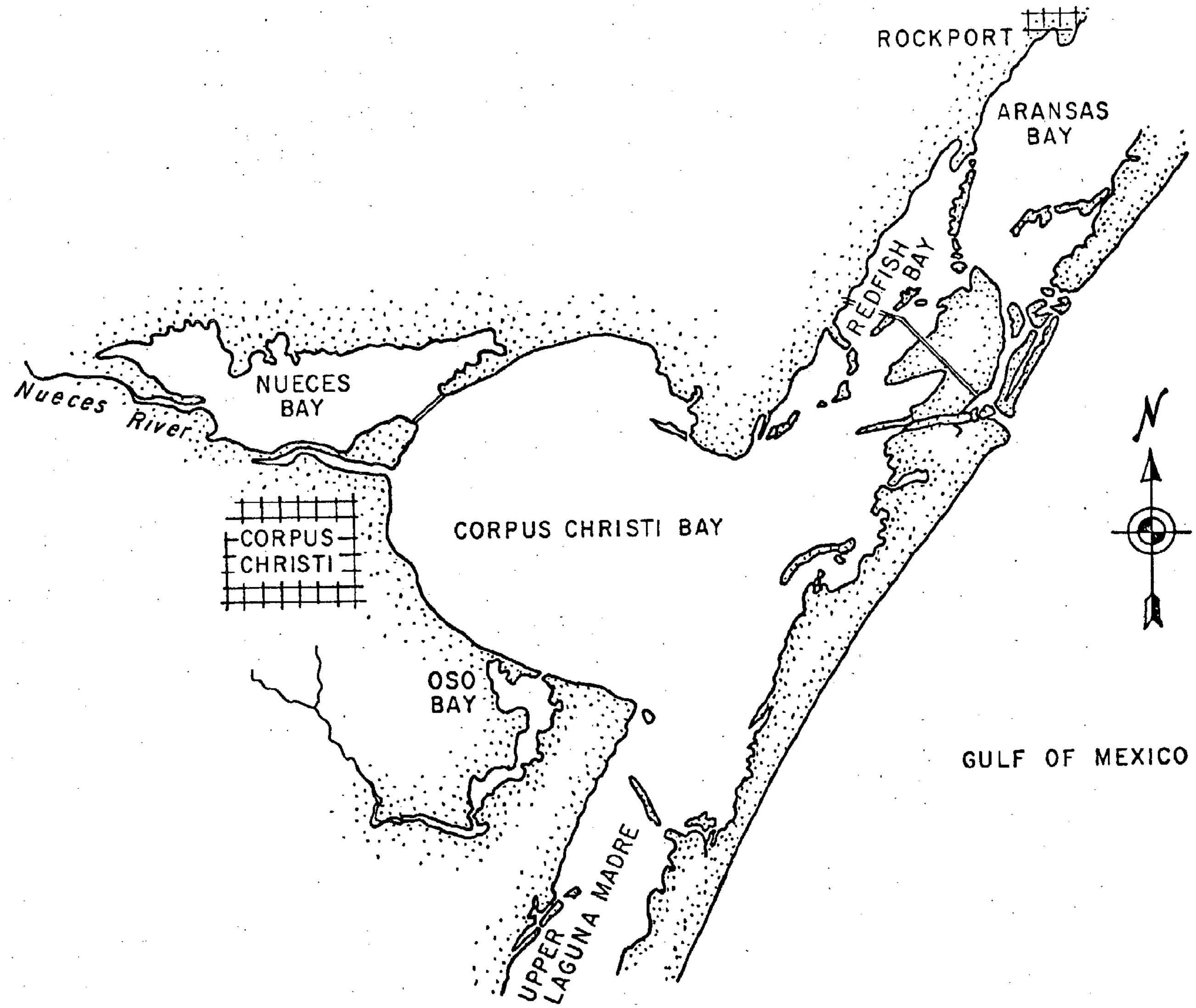


FIGURE A-1
THE CORPUS CHRISTI BAY SYSTEM

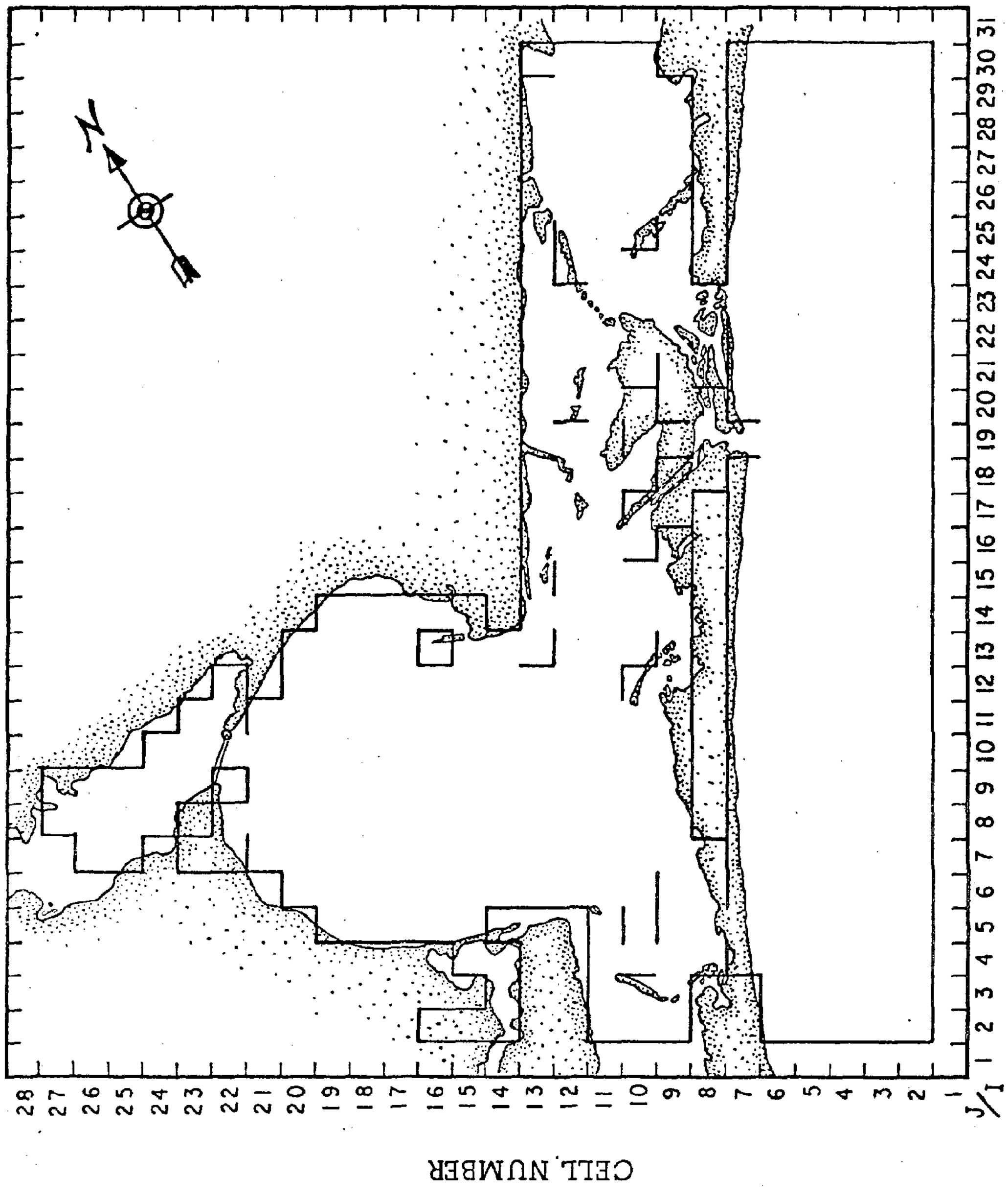


FIGURE A-2
GRID SCHEME

Inflows

A data bank on water use and wastewater generation has been developed by another task force of the project concerned with water needs and waste residuals. The first use of this data was to identify and quantify all known diversions and discharges into the Corpus Christi Bay System. Knowing these inputs, the necessary modifications were made to incorporate this additional data into the Corpus Christi Bay System Model. Figure A-3 shows the location of the inflows presently included in the models and the existing tide gages. Diversion and discharges with flows less than 0.1 cfs have been neglected. Table A-1 is a summary of diversions, discharges and freshwater inflows and the corresponding waste loadings for total dissolved solids, BOD_5, and total phosphorus. Most of these inflows represent an aggregation of flows in the vicinity of a particular cell. Only the major sources are listed for each flow under the description column. Table A-2 is a listing of the location of the tide gages.

Excitation Tides

After preliminary studies with the Corpus Christi Bay System Model, it was obvious that the hydrodynamics of the system could not be properly simulated without some adjustment of the excitation tides at the Laguna Madre and Rockport boundaries. These tidal datum adjustments are due to suspected datum irregularities for some of the tide gages in the Corpus Christi Bay System. Similar difficulties have been previously reported for other estuaries (1). No phase corrections are necessary for any of the excitation tides.

The Gulf excitation tide, which is based on tide gage readings at the Port Aransas Jetties, was held constant while the Laguna Madre excitation tide was shifted vertically downward by 0.26 feet and the Rockport excitation tide was shifted downward by 0.13 feet. This adjustment resulted in reasonable responses of tidally generated flows and net exchange being produced by the model. The observed tides at the boundaries together with the adjusted tides used in the model are presented in Figure A-4 .

Data Packages

Eleven Data Packages were assembled for previous model development for the TWDB Corpus Christi-Aransas-Copano Bays system (2). A review of these data packages revealed that all were deficient except for total dissolved solids in the quantity of water quality data necessary for calibrating (and verifying) the water quality constituent transport models for the Corpus Christi Bay transport models. Hence, the data base was brought up to date by assembling eight "new" Data Packages encompassing the results of field studies by TWDB and USGS from July 19, 1971, to November 16, 1972.

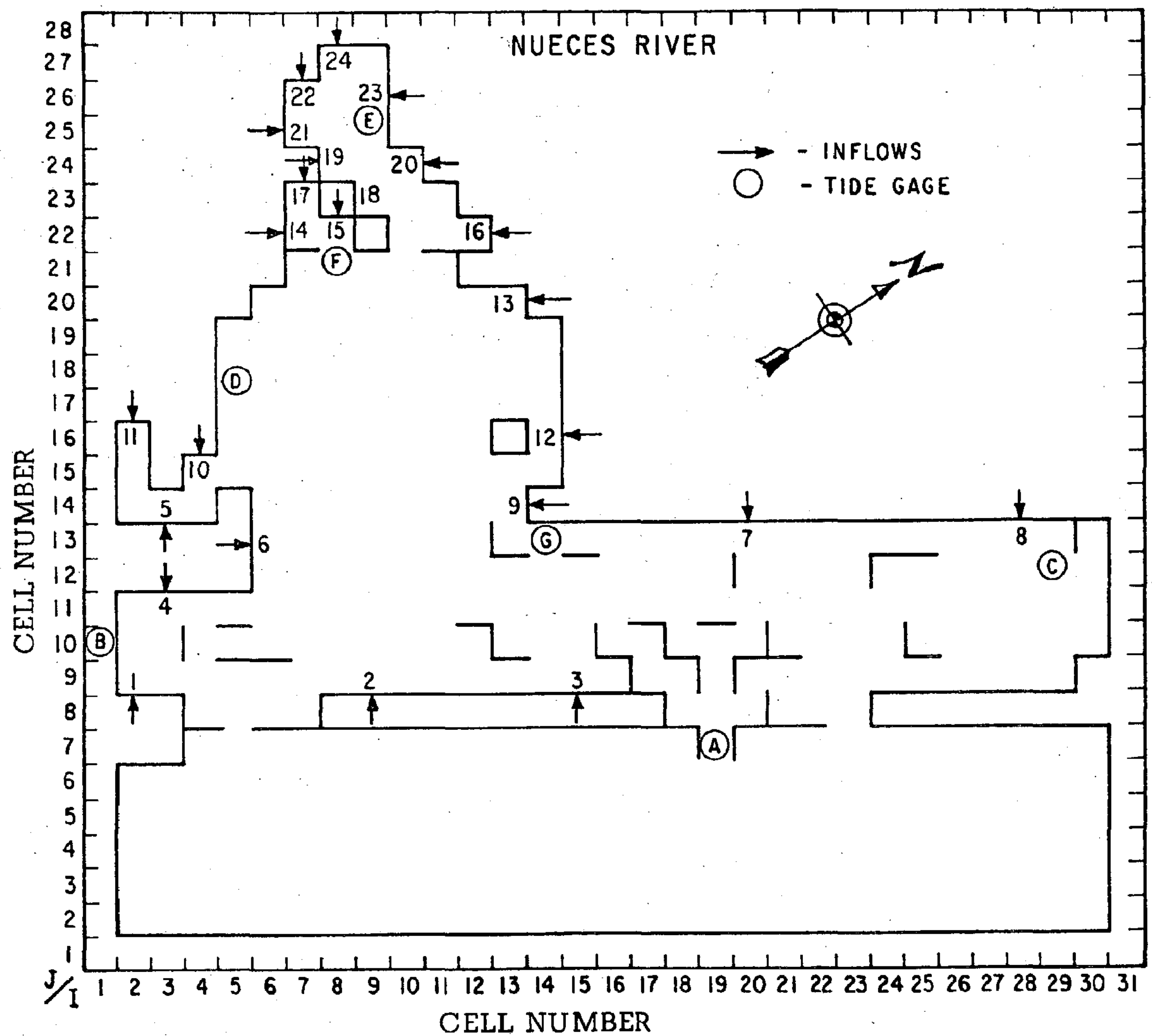


FIGURE A-3
LOCATION OF INFLOWS & EXISTING TIDE GAGES

TABLE A-1
SUMMARY OF INFLOWS

INFLOW NO.	CELL	DESCRIPTION	FLOW (CFS)	TDS (PPT)	BOD_5 (PPM)	TOTAL-P (PPM)
1	I 2J8	Laguna Shores & Flour Bluff STP	0.4	0.9	4.8	8.00
2	I 9J8	Oil Production Facilities	0.2	40.0	455.0	0.01
3	I15J8	Nueces County WCID	1.3	0.9	25.0	8.00
4	I 3J11	Oil Production Facilities	0.3	80.0	230.0	0.01
5	I 3J13	Oil Production Facilities	0.1	80.0	230.0	0.01
6	I 5J13	Naval Air Station	0.2	1.2	38.4	8.00
7	I20J13	Aransas Pass STP	1.1	0.9	70.0	8.00
8	I28J13	Rockport STP	0.8	0.9	7.0	8.00
9	I13J14	Oil Tanker Loading Facility	0.4	1.0	161.0	8.00
10	I 4J15	Oso Creek STP	13.3	0.9	4.0	8.00
11	I 2J16	Oso Creek & Westside STP	5.3	24.0	7.5	1.20
12	I14J16	Ingleside STP	0.3	0.9	20.0	8.00
13	I13J2	Gregory STP	0.3	0.9	100.0	8.00
14	I 6J22	Broadway STP	15.5	0.9	15.0	8.00
15	I 8J22	CPL Diversion	-936.0	31.0	5.9	0.14
16	I12J22	Portland STP	0.7	0.9	4.0	8.00
17	I 7J23	Oil Refinery	6.7	31.0	8.2	0.14
18	I 8J23	CPL Discharge	936.0	30.0	5.9	0.14
19	I 7J24	Oil Refinery	2.2	30.0	8.2	0.14
20	I10J24	Oil Production Facilities	0.5	40.0	27.7	0.01
21	I 6J25	Oil Production Facilities	0.1	40.0	54.4	0.01
22	I 7J26	Nueces River	5.7	4.0	4.2	0.05
23	I 9J26	Oil Production Facilities	1.5	40.0	85.0	0.01
24	I 8J27	Oil Production Facilities	0.1	40.0	139.0	0.01

TABLE A-2
TIDE GAGE LOCATIONS FOR CORPUS CHRISTI BAY SYSTEM MODEL

GAGE IDENTIFICATION	CELL NUMBER	LOCATION
A	I 19J7	Aransas Pass at Port Aransas
B	I 1J10	Laguna Madre near Flour Bluff
C	I29J12	Aransas Bay near Rockport
D	I 5J18	Corpus Christi Bay at 4600 Ocean Dr.
E	I 9J26	Nueces Bay near White's Point
F	I 8J22	Corpus Christi Bay at Corpus Christi
G	I14J13	Corpus Christi Bay at Ingleside

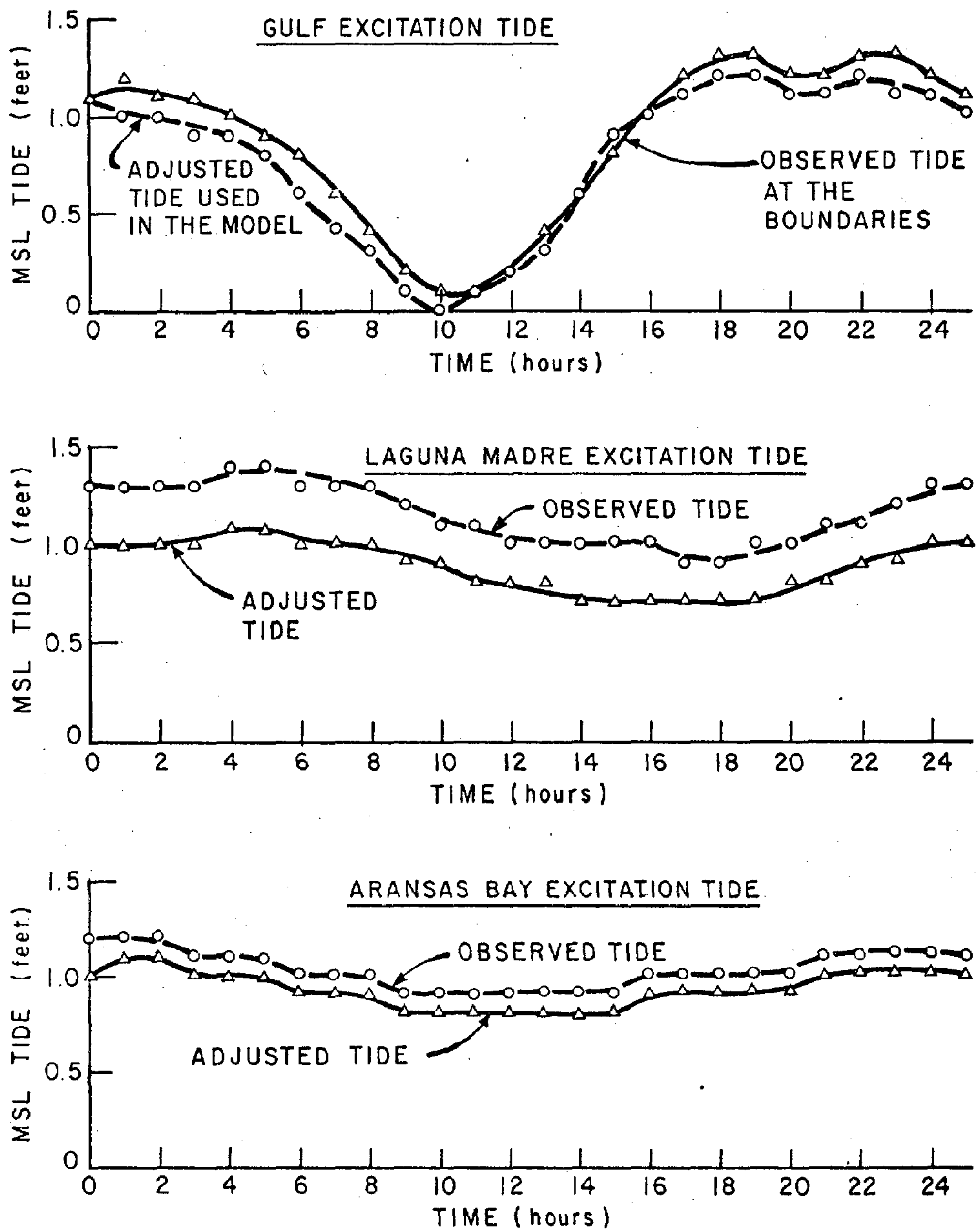


FIGURE A-4
OBSERVED & ADJUSTED TIDES AT THE MODEL'S BOUNDARIES

Table A-3 summarizes the basic data needs for model development, the federal or state agency from which the data were received, the desired consistency of the data and how the data are utilized. Table A-4 is a summary of the sufficiency of the data with respect to the new Data Packages. Data Package XVIII for September 18-20, 1972, was selected as the best Data Package to begin development and calibration of the Corpus Christi Bay System models.

Calibration of Corpus Christi Bay System Models

Having made the necessary modifications to the previously developed TWDB models and assembling new Data Packages, the next step was to calibrate the models. With the development of water quality transport models in mind, the Data Packages were arranged in time so that water quality concentrations were available for initial and final conditions. Hence, the inputs into the model are averages representing the time interval between the dates that water quality data are available. The models have the capability of utilizing instantaneous changes in the inputs; but at present, average inputs are used due to the fact that it greatly simplifies the model calibration process.

The hydrodynamic model was operated to simulate the conditions corresponding to Data Package XVIII. The transport model was operated using the net velocities and average depth output from the hydrodynamic run. As an additional check, the TWDB models for the Corpus Christi-Aransas-Copano Bay system also were operated for the Data Package XVIII. The common responses generated from the TWDB and Corpus Christi Bay models and the observed field data were compared where appropriate.

Figures A-5 and A-6 represent the temporal variations of flow for the x and y-direction of cells I25J9 and I25J11, respectively, over one tidal cycle for both models. These cells are located six miles west of the eastern boundary of the Corpus Christi Bay model. The flows simulated for these cells are in good agreement and are typical of the remaining cells which comprise the model. Figures A-7 and A-8 are vector plots of the net flows (cfs/ft of width) (the basic hydrodynamic input to the mass transport models) for the Corpus Christi Bay and TWDB models, respectively. The agreement between the two models is excellent.

The total dissolved solids simulations from the two models and the observed concentrations for Data Package XVIII are presented in Table A-5. Close agreement was once again produced.

As a further check on the reliability of the Corpus Christi Bay models, both the TWDB and Corpus Christi Bay HYDTID models were run for Data

TABLE A-3
DATA PACKAGE COMPOSITION AND USAGE

TIME SPAN	COOPERATING AGENCY	CONGRUOUS FEATURES	UTILIZATION
1-7 days: Water Quality Data	Texas Water Development Board/ U. S. Geological Survey	1. All constituents measured for substantial number of stations 2. Vertical homogenity	1. Initial concentrations for long term transport/reactive models 2. Needed because models are 2-dimensional areawise
30-90 days: Tides	U. S. Geological Survey	3. Phase and amplitudes uniform	3. Simplifies hydrodynamics
Fresh Water Inputs	U. S. Geological Survey	4. Magnitude constant and low 5. All constituents measured	4. Simplifies hydrodynamics 5. Inputs for transport/reactive models
Diversions	Texas Water Rights Commission	6. Accounted for and quantities known	6. Inputs for hydrodynamics model
Discharges	Environmental Protection Agency Texas Water Quality Board	7. Accounted for and quantities and quality measured	7. Inputs for hydrodynamic and transport/reactive models
Meteorology	U. S. Weather Service	8. Wind steady 9. Evaporation rate steady 10. Low precipitation	8. Simplifies hydrodynamics 9. Simplifies hydrodynamics & input for transport/reactive models 10. Simplifies hydrodynamics & input for transport/reactive models
Water Quality Data	Texas Water Development Board/ U. S. Geological Survey	11. All constituents measured for substantial number of stations 12. Vertical homogenity	11. Final concentration for long term transport/reactive models 12. Needed because models are 2-dimensional areawise

TABLE A-4

SUFFICIENCY OF DATA WITH RESPECT TO NEW DATA PACKAGES

DATA	DATA PACKAGES							
	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX
Initial Water Quality Data	-	+	+	+	+	+	+	+
Vertically Honogenity	-	-	+	+	+	+	+	+
Tides	-	-	+	+	+	+	+	+
River Inputs	+	+	+	+	-	-	+	-
River Constituents Data	+	+	+	+	+	+	+	+
Diversion Data	0	0	0	0	0	0	0	0
Discharge Data	0	0	0	0	0	0	0	0
Wind Data	+	+	+	+	+	+	+	+
Evaporation Data	+	+	+	+	+	+	+	+
Precipitation	+	+	+	-	-	-	+	+
Final Water Quality Data	+	+	+	+	+	+	+	+

\+ Data or Conditions Sufficient
\- Data or Conditions Not Sufficient
0 Estimates Provided by Water Needs & Residuals Management Task Force

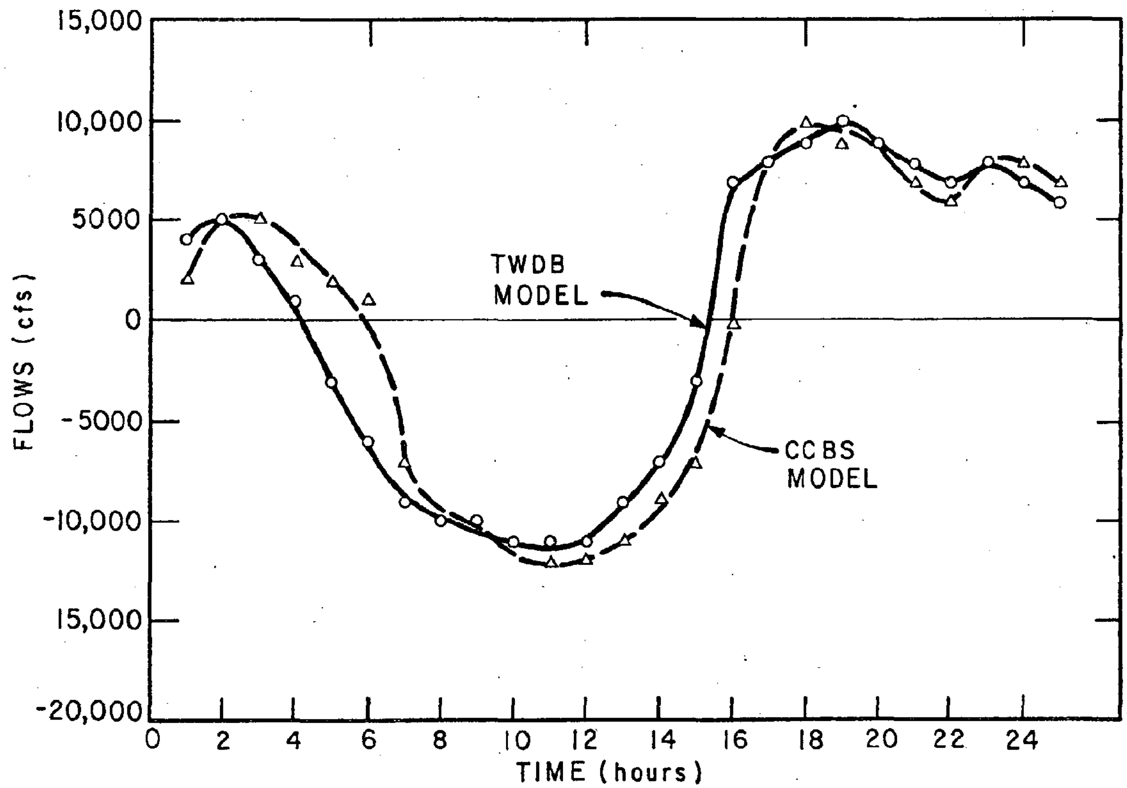


FIGURE A-5
COMPARISON OF MODELS' SIMULATION OF X FLOW
IN CELL I25J9 FOR DATA PACKAGE XVIII

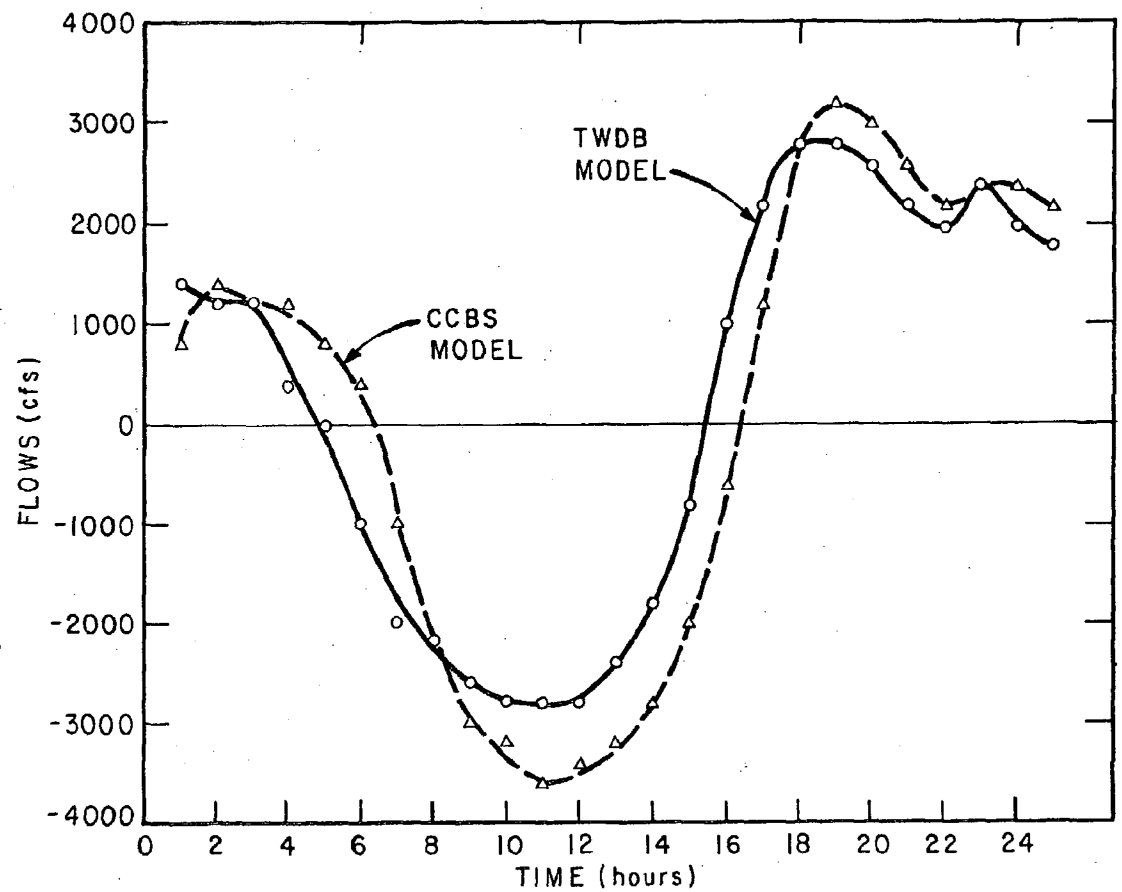


FIGURE A-6
COMPARISON OF MODELS' SIMULATION OF Y FLOW
IN CELL I25J11 FOR DATA PACKAGE XVIII

FIGURE A-7
SIMULATED NET FLOWS FOR THE CORPUS CHRISTI BAY SYSTEM MODEL

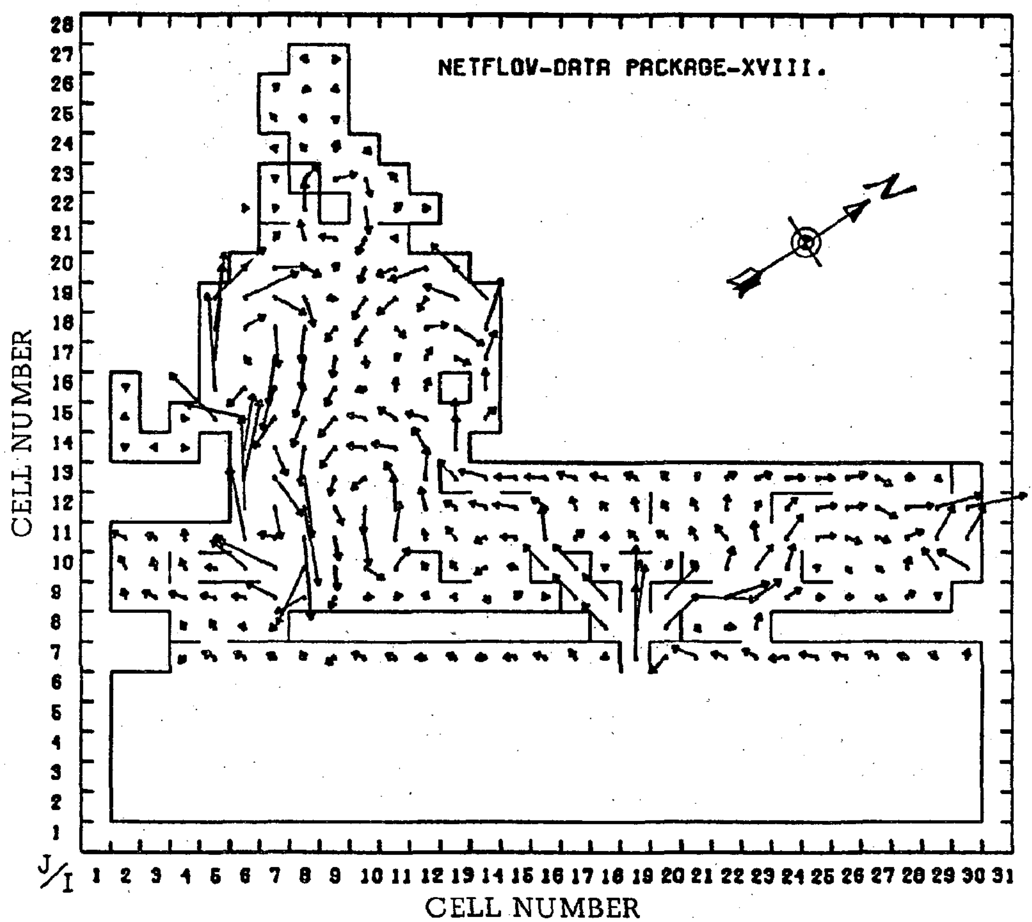
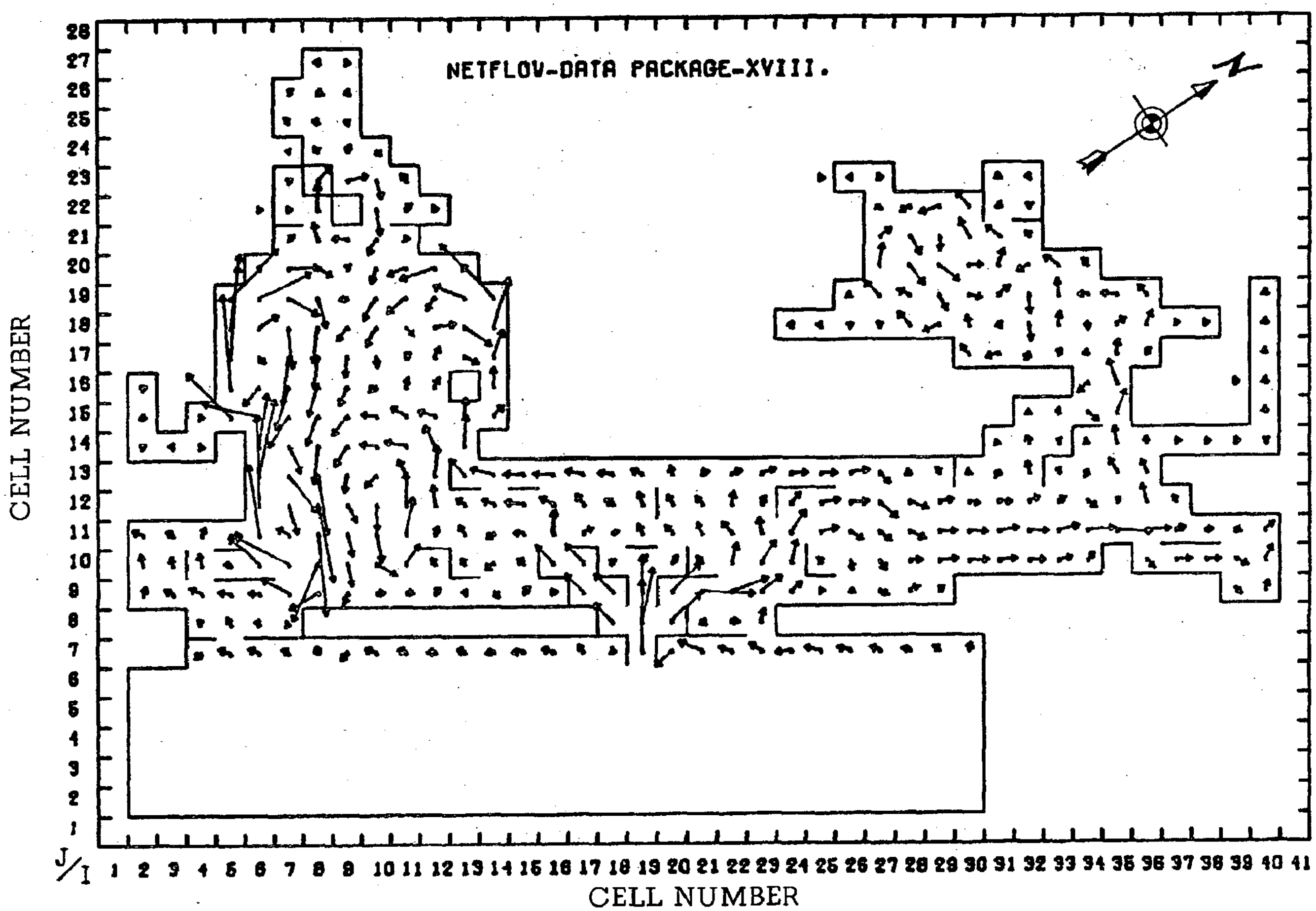


FIGURE A-8
SIMULATED NET FLOWS FOR THE TWDB MODEL



Package XI (2). Data Package XI is a unique Data Package in that field measurements of the net flows and tidal exchanges were made by the TWDB and USGS at ten selected locations where the physiography of the bay system was such to enable these measurements to be made easily. The TWDB HYDTID was calibrated for this Data Package previously (2) and represents a high degree of calibration for the composite system model because actual flow measurements were made that could be compared with the corresponding responses produced by the model. Figures A-9 through A-12 compare the flow predictions of the two models at four cells together with the field measurements. The Corpus Christi Bay model produces responses that are in close agreement with both the TWDB model and the observed data. [The transport model, LOTRAN, was not run for comparison with this Data Package because vertical homogenity, a necessary condition for the operation of LOTRAN, was not indicated.]

TABLE A-5

COMPARISON OF OBSERVED AND COMPUTED TOTAL DISSOLVED SOLIDS CONCENTRATION FOR DATA PACKAGE XVIII

	Total Dissolved Solids Concentrations (PPT.)		
Cell Number	TWDB Model	Corpus Christi Bay System Model	Observed
I 9J25	30.9	30.9	30.4
I 9J24	30.6	30.7	30.2
I 7J22	29.7	30.7	32.1
I 9J19	30.4	31.3	32.7
I 6J18	31.2	31.0	32.0
I11J19	30.7	31.8	32.8
I 8J12	32.2	32.5	32.9
I12J13	31.2	31.7	32.1
I14J11	32.1	32.5	32.1
I27J12	30.2	29.2	28.4
I27J9	31.0	29.5	29.0

FIGURE A-9
COMPARISON OF MODELS' SIMULATION AND OBSERVED DATA OF X FLOW IN CELL I3J9 FOR DATA PACKAGE XI

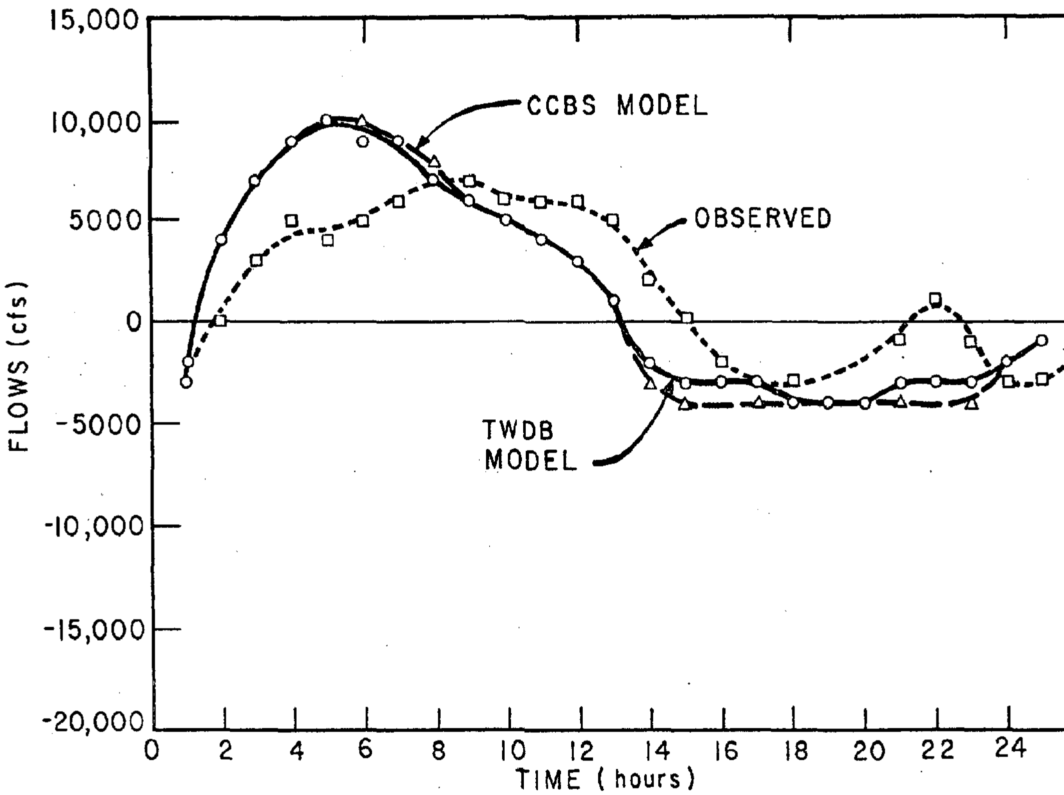


FIGURE A-10
COMPARISON OF MODELS' SIMULATED AND OBSERVED DATA OF
X FLOW IN CELL I18J9 FOR DATA PACKAGE XI

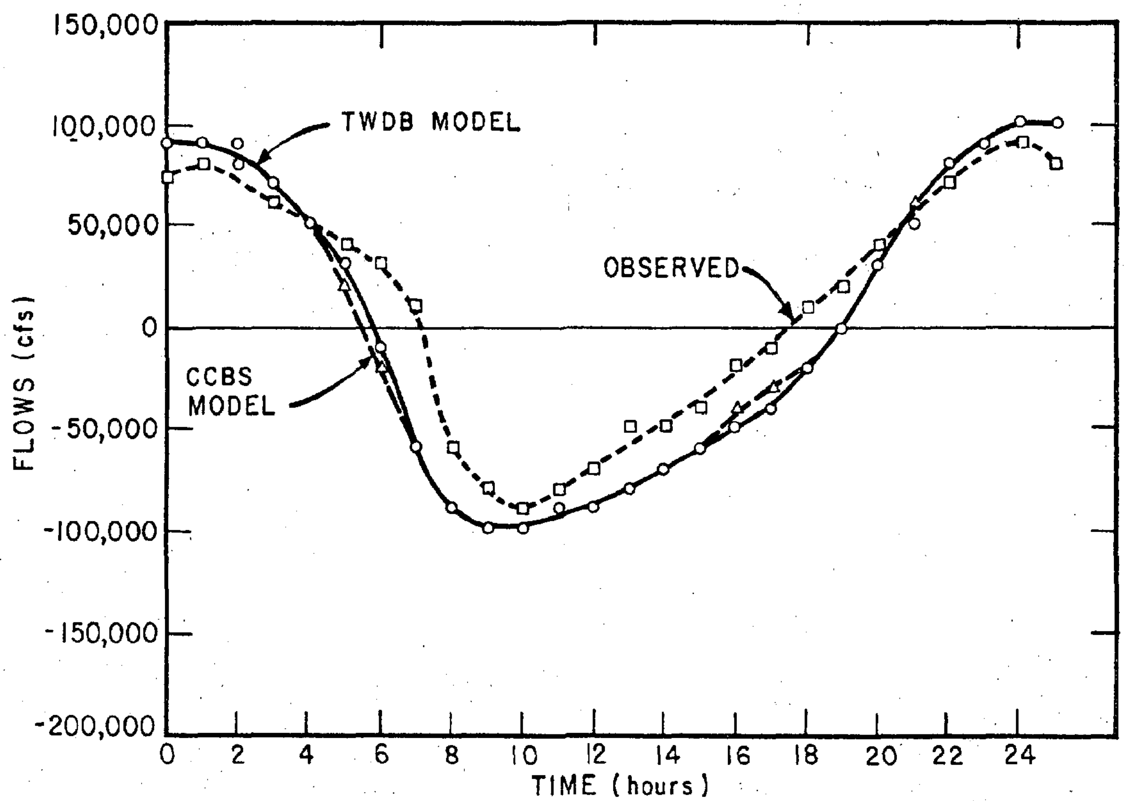


FIGURE A-11
COMPARISON OF MODELS' SIMULATION OF Y FLOW
IN CELL I25J11 FOR DATA PACKAGE XI

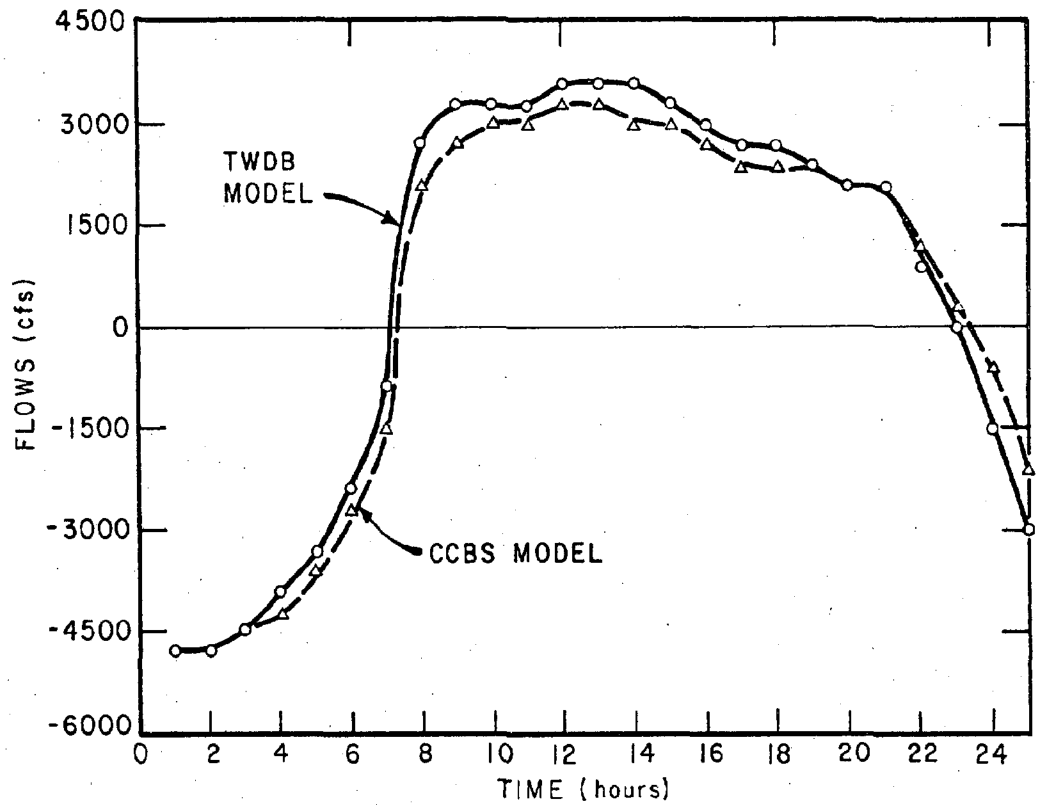
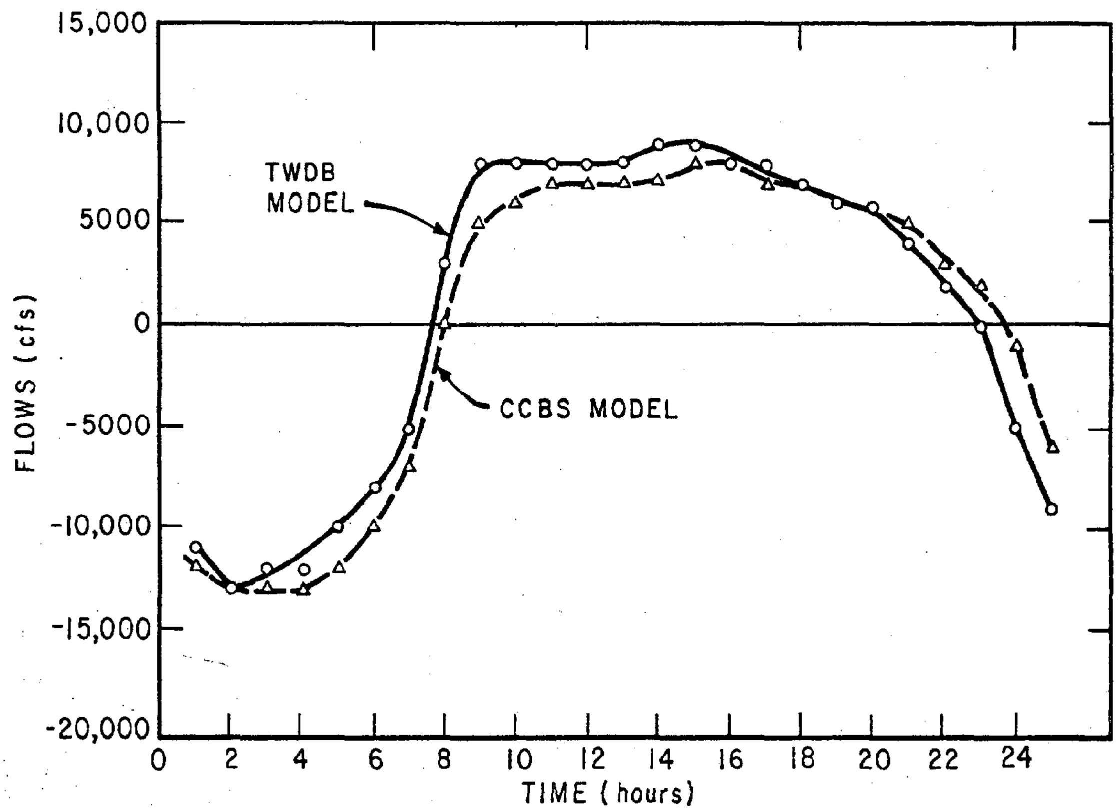


FIGURE A-12
COMPARISON OF MODELS' SIMULATION OF X FLOW
IN CELL I25J10 FOR DATA PACKAGE XI



APPENDIX B
SENSITIVITY ANALYSIS

The basic inputs for the water quality transport models currently under development are the net flows and depths computed from the tidal hydrodynamic model. Due to the importance of these parameters to the operation of the water quality transport models, a high degree of reliability in the computations of the hydrodynamic and transport model needed to be established.

The relative sensitivity of the models to changes in the coefficients has been analyzed by comparing the computed hydrodynamic and transport parameters at selected cells. The parameters are tidal amplitudes, flows in each of the two coordinate directions, and TDS concentrations. Difficulties are encountered when an attempt is made to generalize the sensitivity of the basic model outputs to variations in each coefficient as there are 357 computational cells in the model. A complete analysis of the effects of changes on each cell is impractical; therefore, certain cells were selected as examples upon which the analysis will be based. These cells are considered representative of the unique areas of the Corpus Christi Bay system. Where available the analyses are compared to observed data.

Hydrodynamics

The TWDB hydrodynamic model (2) was run for the time period in which the most complete set of observed data were in existence. This period has been designated as Data Package XI and encompasses the six days from November 5-10, 1971. During this period, the observed data included Gulf excitation tides, measured tides at various points within the bay system, measured fresh water inflows, industrial withdrawals and return flows, wind magnitudes and directions, and the necessary meterological observations from which evaporation rates could be determined.

In addition, Data Package XI contains net flows and tidal exchange measurements at ten selected locations where the physiography permitted these observations to be made. Locations such as narrow channels and bridge constrictions were utilized for this purpose. The reliability of the simulations for this time period was considered to be the best available (2).

Hydrodynamic Wind Stress Coefficient

The wind stress coefficient, K_W, is assigned a value of 0.006 in the calibrated hydrodynamic model. Additionally, the values of K_W of 0.0006 and 0.06

were investigated and compared with the calibrated models' responses. During the simulated time period, wind speed and direction were changing so that in testing the sensitivity of the model to changes in K_W, the output responses were assessed over a wide range of varying wind inputs.

The effect of changes in K_W on tidal amplitudes was investigated for several cells with varying depths and locations in the system. Generally for cells with depths exceeding 10 feet, changes in K_W produced relatively insignificant differences in the responses, whereas for smaller depths, the changes were more pronounced.

Figure B-1 is a plot showing temporal changes in tidal amplitude for cell I10J24 over one tidal cycle. Cell I10J24 is a shallow cell with a depth of 3 feet located in Nueces Bay. As can be seen, the tidal amplitude for shallow cells is sensitive to variations in K_W. Values of K_W of 0.0006 and 0.006 produce essentially the same tide while a K_W of 0.06 produces an erratic tide. The observed tide gage values for the simulated tide period are also plotted. The differences in mean tide elevations between the computed and observed values is believed to be caused by datum irregularities associated with this gage. Notice, however, that the phases of the tides using K_W equal to 0.0006 and 0.006 are the same as the observed tide.

Figure B-2 represents the tidal amplitude for cell I6J13, a cell with a depth of 12 feet. This cell is located on the west side of Corpus Christi Bay at the Naval Air Station. The tidal amplitude response for this cell is typical of most of the cells in the bay. The correlation between the observed data and the simulated tides is good.

The flows in the coordinate directions respond in much the same manner as the tidal amplitudes to changes in values of K_W. Figure B-3 is a plot of the flow in the X-direction for cell I3J11, a cell with a depth of 4 feet. A K_W equal to 0.06 produces a radically different response than the other values of K_W. The shape, phase, and amplitudes produced by a K_W of 0.06 in no way resembles the responses of the other two values or the observed flows. For this cell the observed flows are considerably different than those predicted by the model. This is not the general case. In most cases where observed flows are available there are good correlations with predicted values. Figure B-4 presents the flows in the Y-direction for cell I19J7, this is a cell with a depth of 28 feet representing the Port Aransas Channel. The correlations here are excellent. K_W equal to 0.06 yields a response slightly different; however, the phase and shape differ only by a small amount.

Manning's Roughness Coefficient

The second coefficient which was investigated was the Manning roughness coefficient, n. In the calibrated model a unique value of n is assigned to each

FIGURE B-1
CHANGE OF WIND STRESS COEFFICIENT ON TIDAL AMPLITUDES
FOR A SHALLOW CELL WITH A DEPTH OF THREE FEET

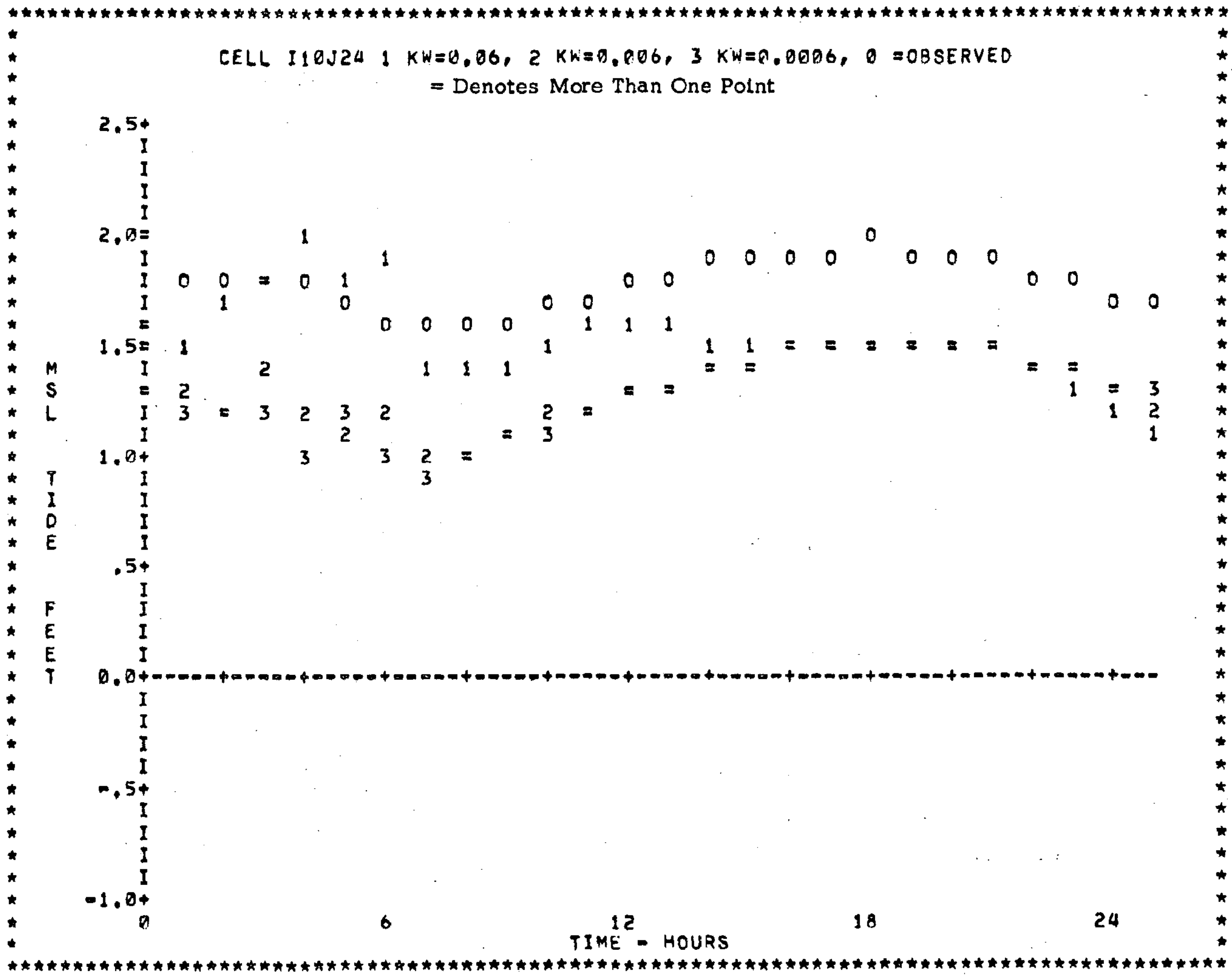
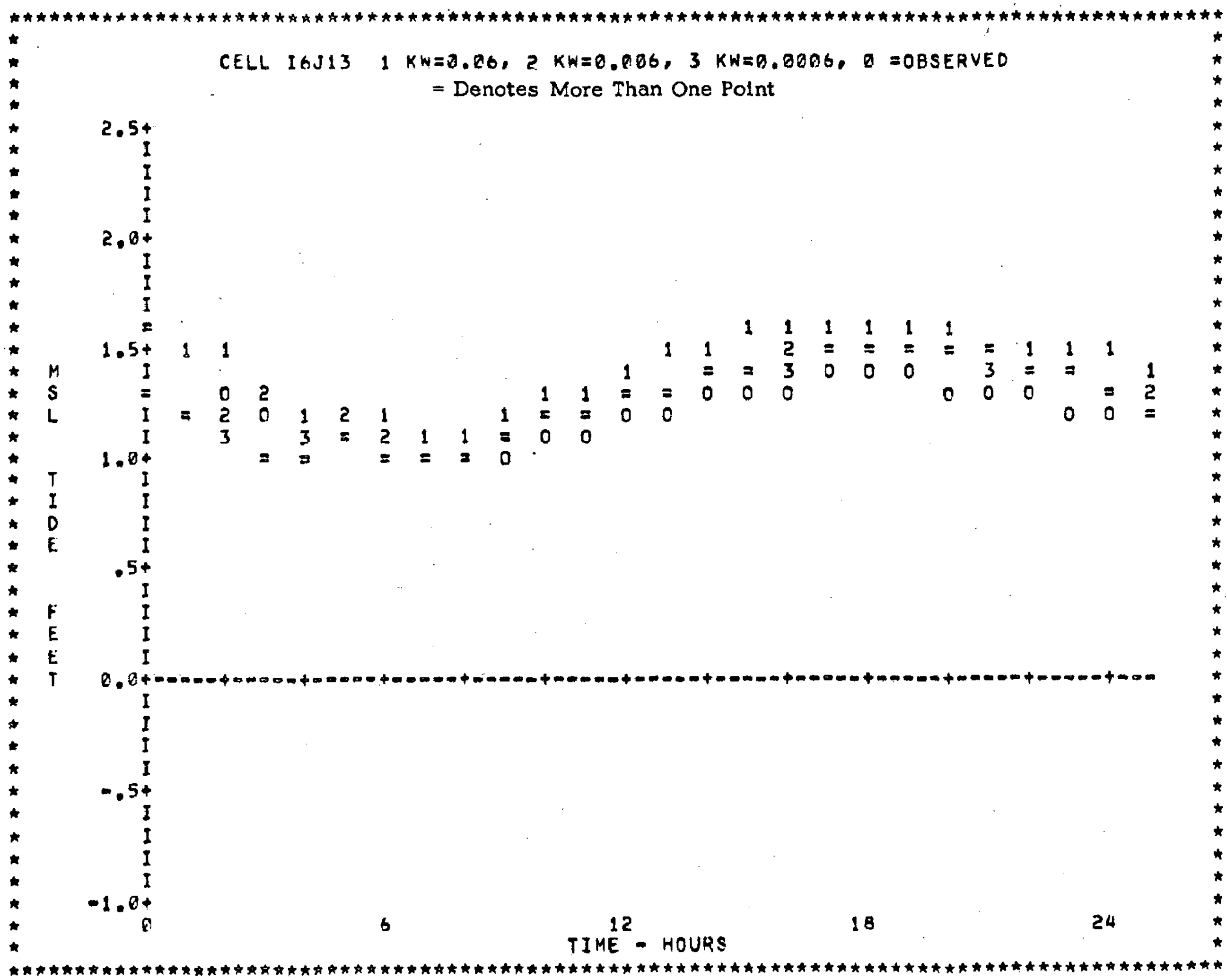


FIGURE B-2

CHANGE OF WIND STRESS COEFFICIENT ON TIDAL AMPLITUDES FOR A TYPICAL CELL WITH A DEPTH OF TWELVE FEET



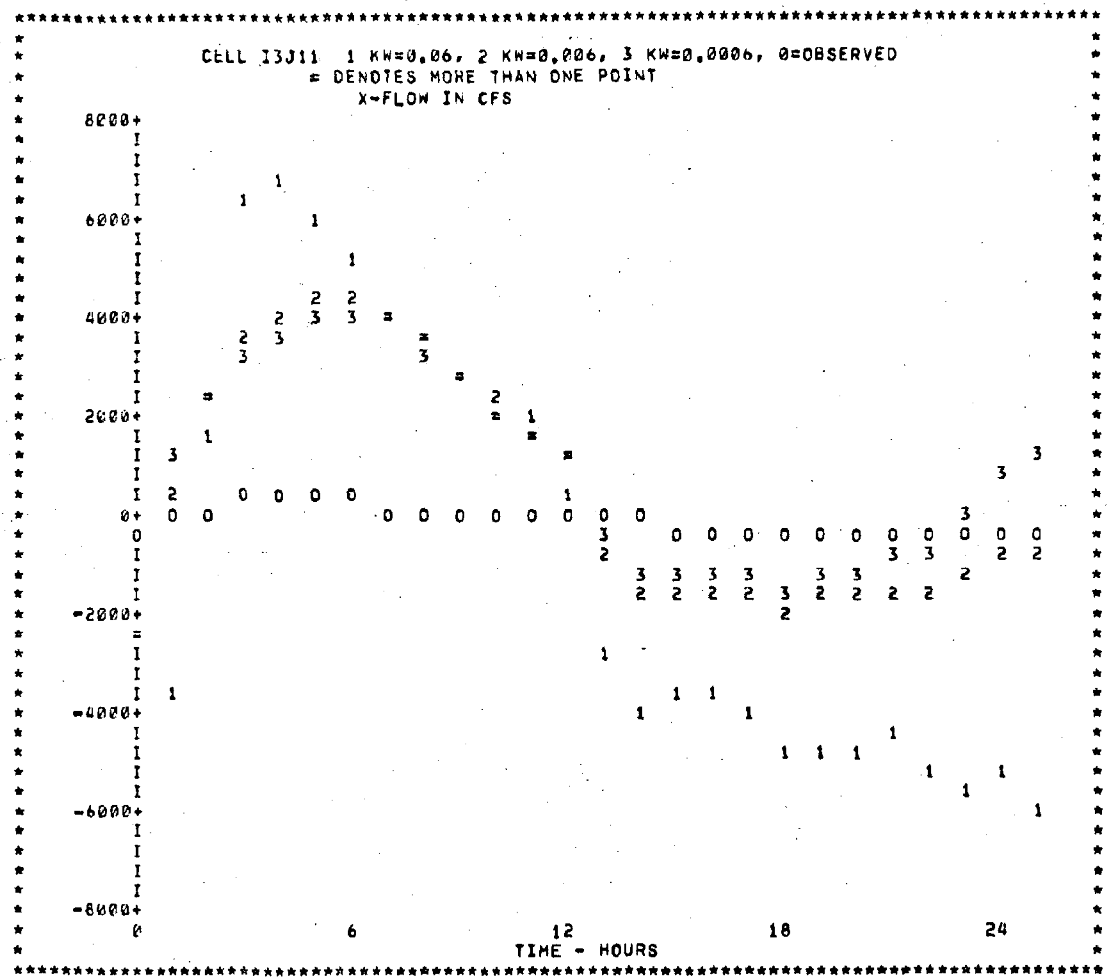


FIGURE B-3
CHANGE OF WIND STRESS ON FLOW IN THE X DIRECTION
FOR A SHALLOW CELL WITH A DEPTH OF 4 FEET

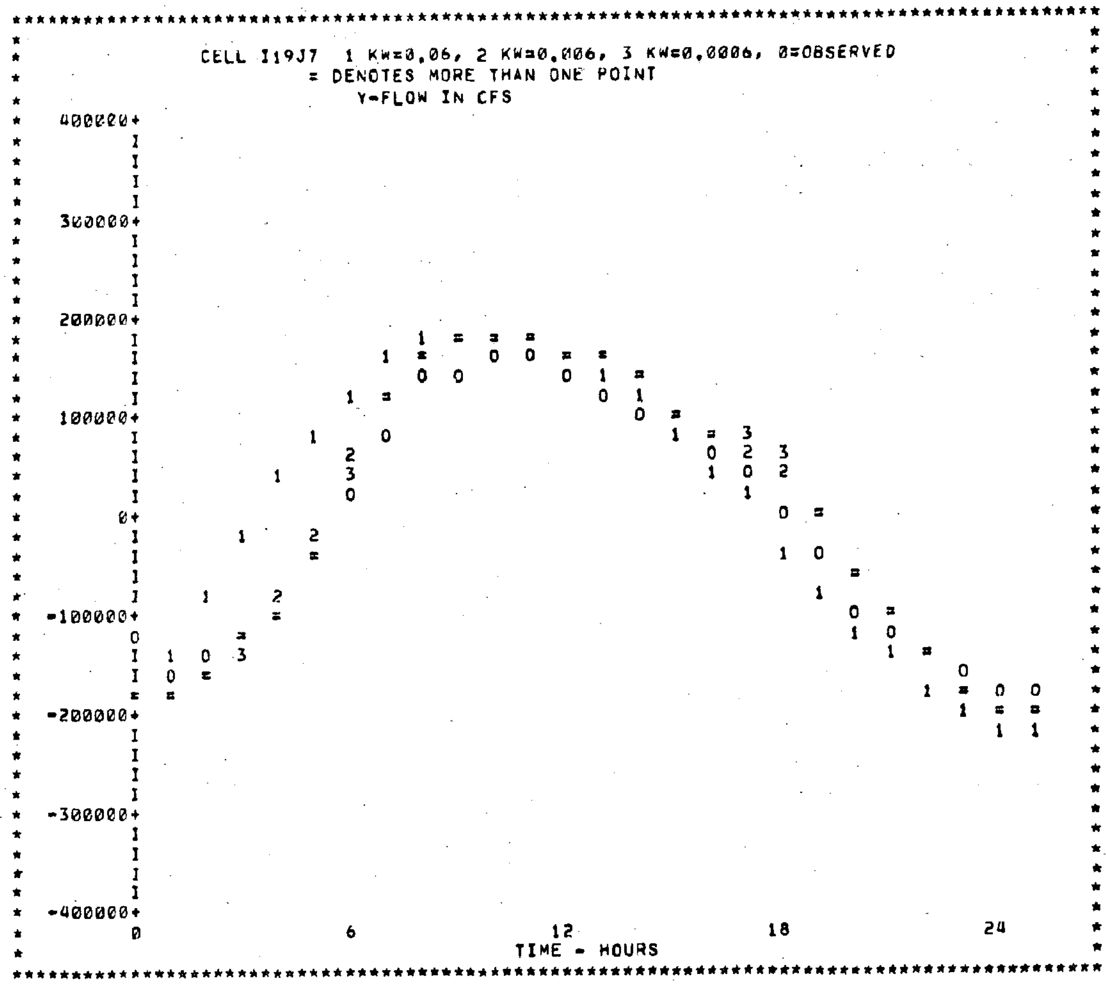


FIGURE B-4
CHANGE OF WIND STRESS COEFFICIENT ON FLOW IN THE Y DIRECTION FOR A CHANNEL CELL WITH A DEPTH OF 28 FEET

cell based primarily on the depth of the cell. An average value of n equal to 0.025 assigned to each cell yields responses which are essentially the same as those which result from assigning a unique value of n to each cell. The sensitivity of the model to variations in n was determined for the cases where n was set to 0.015, 0.025, and 0.035 for each cell.

Figure B-5 depicts the changes in flows for cell I10J21, a 9 foot deep cell wherein the flow between Nueces Bay and Corpus Christi Bay is represented. A general relationship between the Manning n and the magnitudes of the flood and ebb flows is apparent. Decreasing the coefficient increases the amplitudes and vice versa. Figure B-6 represents a 13 foot deep cell, I10J14, in Corpus Christi Bay. The same trend is apparent here. Figure B-7 presents the effects of changes of n on the flow through the Port Aransas Channel. Once again the same trend is noted. The correlation at this station with the observed flows is excellent.

Evaporation Coefficient

The third coefficient investigated was the monthly evaporation coefficient. The model was operated with evaporation rates computed from the two extreme monthly evaporation coefficients and the coefficient appropriate for the time period being simulated. This resulted in daily evaporation rates of 0.14, 0.30, and 0.35 inches per day.

Changes in the evaporation rate cause little effect on tidal amplitude as the volume of water evaporated from the bay surface is made up by water from the Gulf. However, local instantaneous velocities do change as do the net flows integrated over a tidal cycle. The change is most apparent at the Gulf passes where the exchange is directly proportional to the difference between total evaporation from the bay surface and inflow into the bay.

Hydrodynamics and Conservative Transport

The slowly-varying mass transport model, LOTRAN, is the basic model which will be used to simulate the water quality constituents. This model has been used previously for the transport of total dissolved solids (2). Modifications have been made in LOTRAN, primarily in the S_i term of the basic convective-dispersion equation, to account for the various reactions of water quality constituents. As with the tidal hydrodynamic model, a certain degree of confidence in the transport model was deemed desirable before proceeding with the additional water quality simulations. To attain this confidence, a sensitivity analysis was undertaken based on changes in the coefficients in the transport model.

FIGURE B-5
CHANGE OF MANNING COEFFICIENT ON FLOW IN THE
Y DIRECTION FOR A NINE FEET DEEP CELL

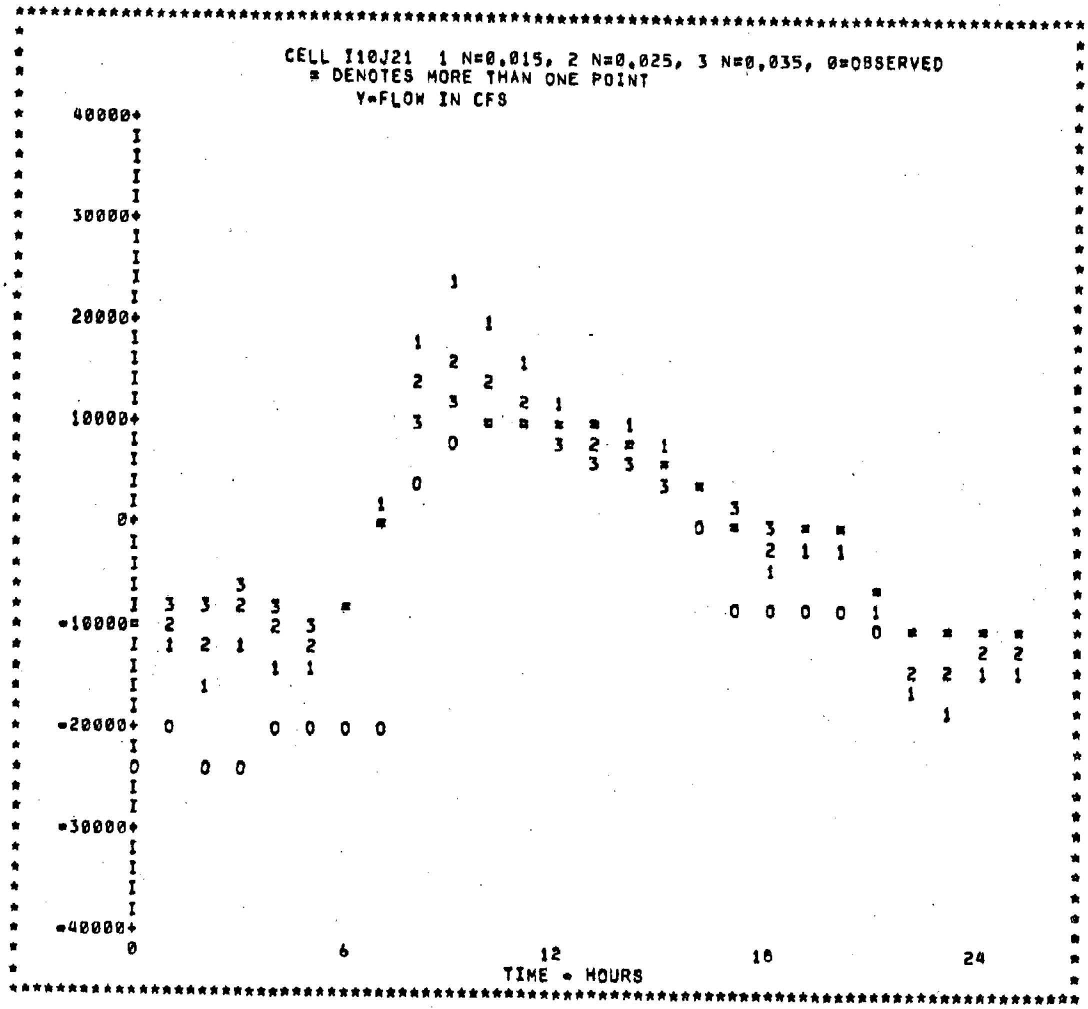


FIGURE B-6
CHANGE OF MANNING COEFFICIENT ON FLOW IN THE
X DIRECTION FOR A THIRTEEN FEET DEEP CELL

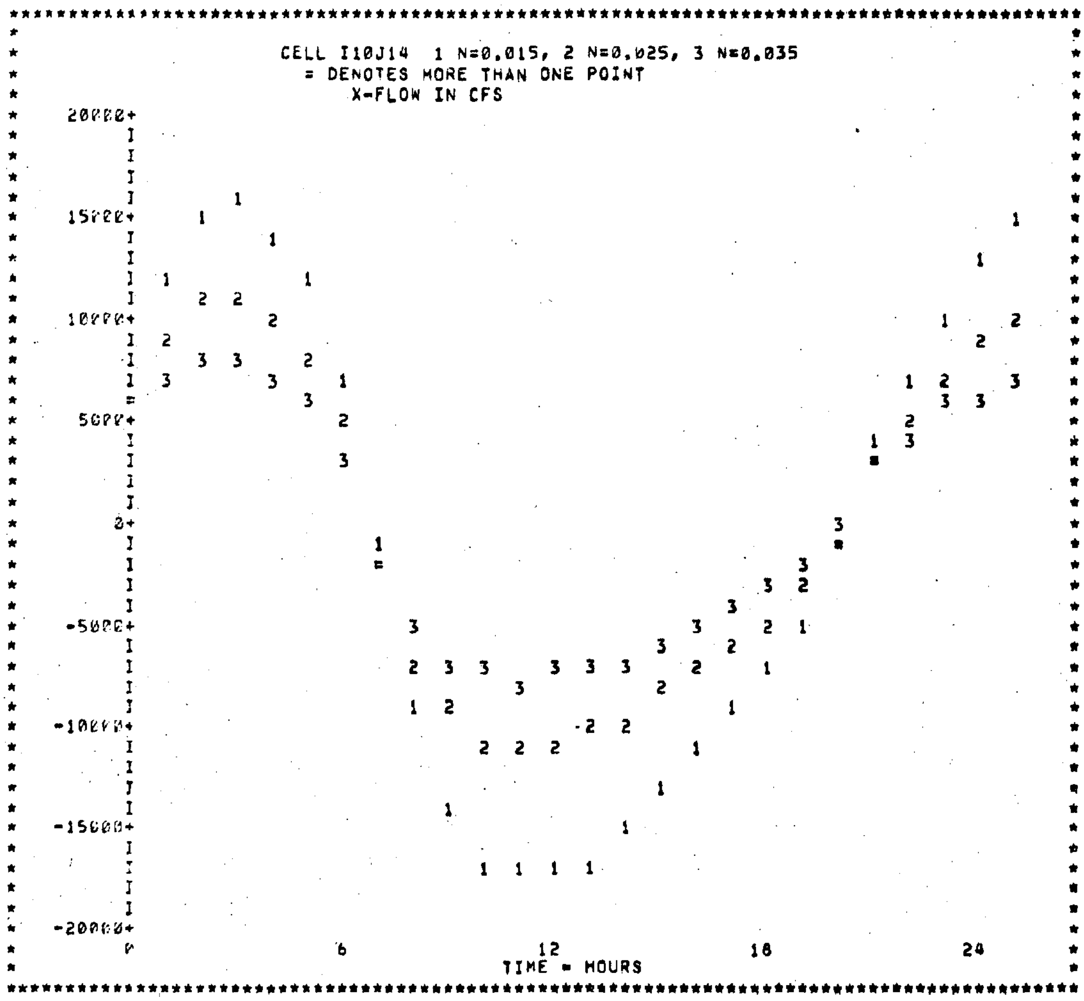
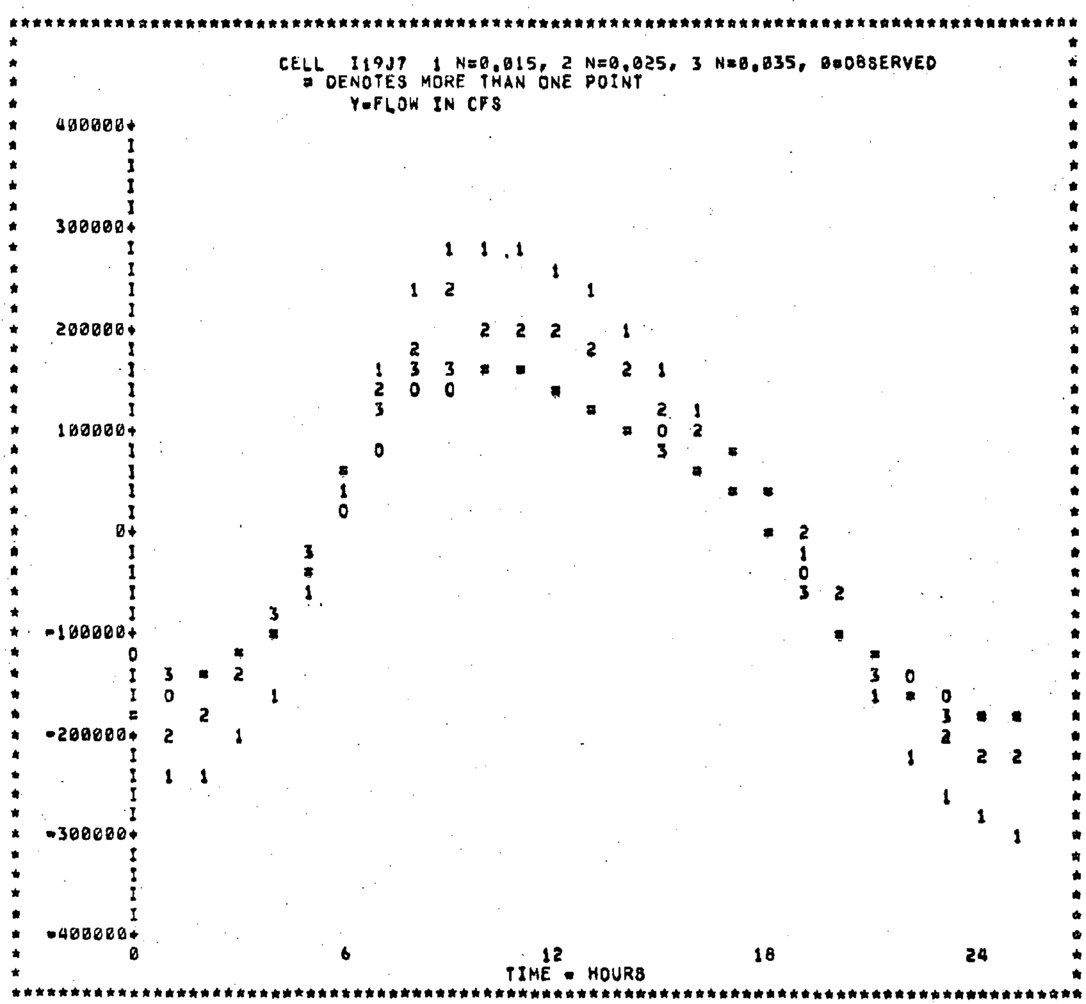


FIGURE B-7
CHANGE OF MANNING COEFFICIENT ON FLOW IN Y DIRECTION
FOR CELL REPRESENTING PORT ARANSAS CHANNEL



The convective-dispersion equation used in LOTRAN for the simulation of total dissolved solids concentrations is of the following form:

$$\frac{\partial(C\bar{d})}{\partial t} + \frac{\partial(\bar{q}_x C)}{\partial x} + \frac{\partial(\bar{q}_y C)}{\partial y} = \frac{\partial}{\partial x}\left[E_x \frac{\partial(C\bar{d})}{\partial x}\right] + \frac{\partial}{\partial y}\left[E_y \frac{\partial(C\bar{d})}{\partial y}\right] + K_e C\bar{d} \qquad \text{(B-1)}$$

As can be seen there are two coefficients of interest in eq. B-1 , the dispersion coefficient, E, and the evaporation rate coefficient, K_e. The sensitivity analysis of LOTRAN involves determining the changes in the responses of the computed total dissolved solids concentrations to changes in these coefficients.

Dispersion Coefficient

The calibrated LOTRAN has assigned values of 3500 ft^2/sec for the dispersion coefficients throughout most of the open bay, slightly higher values at the Gulf inlets, and assigned values of 200 ft^2/sec at the inflow locations. For the sensitivity analysis, the TWDB model was run to simulate conditions corresponding to Data Package III (2). The dispersion coefficients were held constant at the Gulf inlets and at the inflow points while the dispersion coefficients for the remaining cells were set equal to 500, 3500, and 5000 ft^2/sec for three separate runs. The resulting TDS concentrations for eight selected cells (seven of which have field observations for comparison) have been summarized in Figures B-8 and B-9. The results show that dispersion coefficients of 3500 to 5000 ft^2/sec adequately simulate the TDS concentrations in the system and a dispersion coefficient of 500 ft^2/sec predicts values approximately 40 percent higher than the calibrated model.

Evaporation Coefficient

The sensitivity analysis for the evaporation rate coefficients was made using the Corpus Christi Bay HYDTID and LOTRAN models for conditions corresponding to Data Package XVIII. The evaporation rate coefficients are based on an empirically determined monthly rate constant determined from pan coefficients. The computed evaporation rate for this Data Package is 0.29 inches/day. For the sensitivity analysis, both models were run with evaporation rates of 0.40, 0.30, 0.20, and 0.10 inches/day; these correspond to pan coefficients of 1.29, .97, .65, and 0.32 respectively. The results of this sensitivity analysis are summarized in Table B-1. They indicate that realistic evaporation rates must be included to adequately predict the TDS concentrations, but that the computed TDS concentrations are relatively insensitive to the pan coefficient.

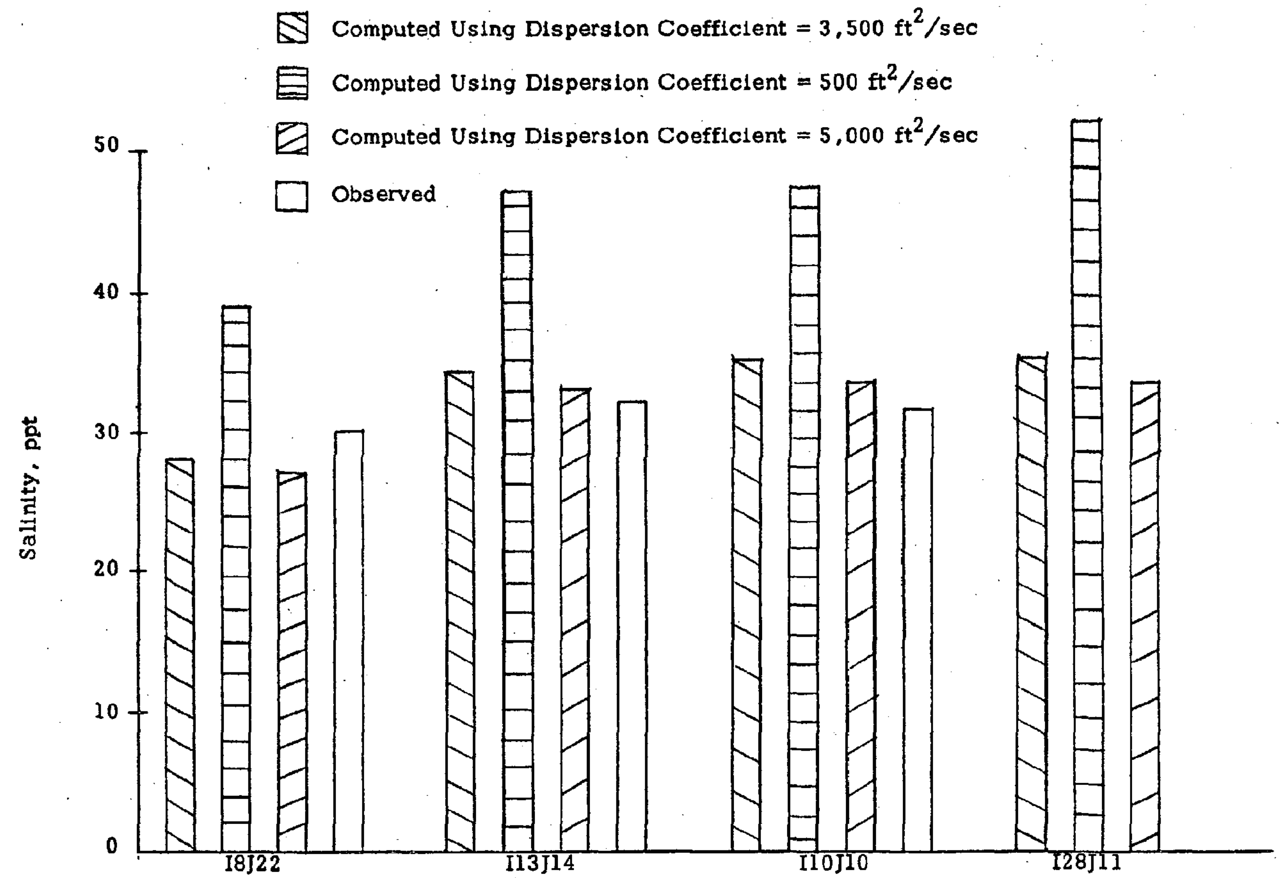


FIGURE B-8
COMPARISONS OF MEASURED & COMPUTED SALINITIES

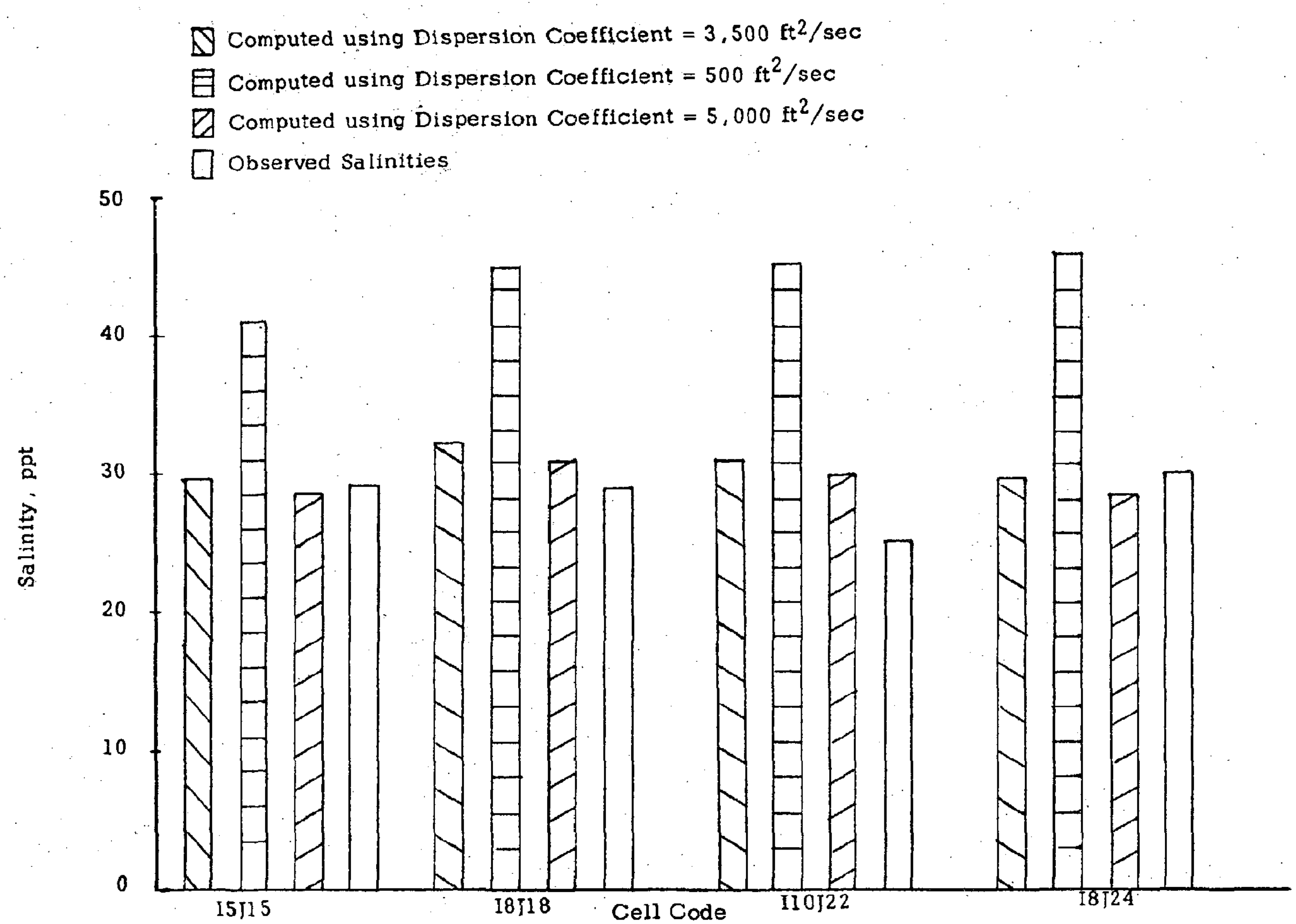


FIGURE B-9
COMPARISONS OF MEASURED & COMPUTED SALINITIES

TABLE B-1
TOTAL DISSOLVED SOLIDS CONCENTRATION (ppt)

Cell Identification	Evaporation Rate (inches/day) 0.10	0.20	0.30	0.40	Observed
I 6J19	29.6	30.6	31.7	32.8	32.0
I 7J9	32.1	32.9	33.8	34.7	33.1
I 7J12	30.7	31.6	32.6	33.6	31.9
I 7J23	29.1	29.4	29.8	30.2	32.1
I 8J24	29.7	30.2	30.8	31.3	30.2
I 8J25	29.7	30.3	31.0	31.7	30.4
I 9J20	29.4	30.4	31.4	32.5	32.7
I11J20	29.2	30.2	31.2	32.4	32.8
I12J14	29.8	30.8	31.8	32.8	32.1
I13J11	30.8	31.7	32.6	33.6	32.1
I29J9	29.1	29.3	29.5	29.7	29.0
I26J12	28 8	29.0	29.2	29.4	28.4

REFERENCES

(1) Masch, F. D., et al, "Tidal Hydrodynamic and Salinity Models for San Antonio and Matagorda Bays, Texas", Report to the Texas Water Development Board, June 1971, 130 pp.

(2) Masch, F. D., et al, "Tidal Hydrodynamic and Salinity Models for Corpus Christi and Aransas Bays, Texas", Report to the Texas Water Development Board, September 1972, 98 pp.